U.S. Department of Justice
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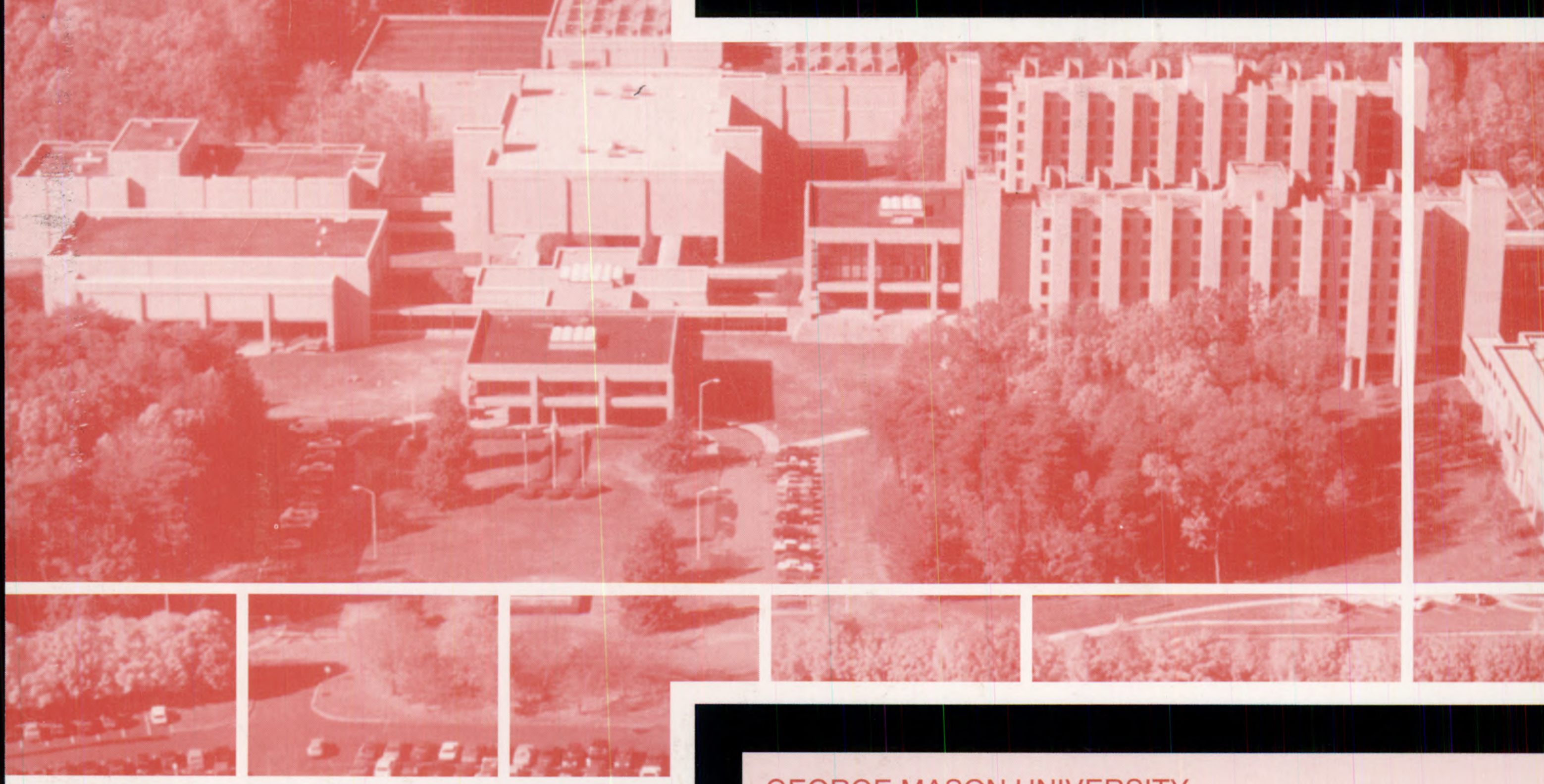
PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON THE FORENSIC ASPECTS OF ARSON INVESTIGATIONS



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PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON THE FORENSIC ASPECTS OF ARSON INVESTIGATIONS

Host
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CONTENTS

SECTION I - LECTURES

SECTION II - EXTENDED ABSTRACTS

Section I
Lectures

Historical Perspective on Arson Evidence

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This paper is the result of a historical analysis which traces the evolution of our scientific knowledge as it relates to fire and arson investigation.

Rather than offering a cursory treatment of a wide range of material which might prove redundant to previous symposia lectures, this paper seeks to limit its scope in terms of subject matter while offering a detailed examination of certain aspects of arson evidence. Therefore, the term arson evidence will be operationally defined as physical evidence which tends to prove that the cause of a fire was arson. The research is further limited to evidence which indicates the use of flammable liquids thought to have been used as an accelerant, since this appears to be the single most sought-after evidence at the fire scene.

While criminalists are no doubt thoroughly familiar with laboratory tests employed for the purpose of identifying such liquids, many may not be familiar with the "nonremovable" evidence observed at the fire scene which led investigators to collect samples they believed contained residue of a flammable liquid. Therefore, the paper offers an understanding of the knowledge involved in the decision of investigators to collect such evidence and how that knowledge has evolved. It may also help to better understand why laboratory analyses so often fail to confirm the presence of flammable liquids despite the strong conviction of investigators that it was used to accelerate the fire.

BACKGROUND

Since this evidence is generally discovered during the civil fire investigation (the investigation which seeks to determine the cause of a fire) and not the criminal arson investigation (which seeks to prove a person's guilt), some background on fire investigation is offered.

Determining the cause of a fire was an art that, according to Cote and Bugbee (1988), dates back to at least 300 B.C. in Rome where "Roman law decreed that the Quarstionarius—the Roman equivalent of today's state fire marshal—determines the cause of all fires." Despite such an early beginning, the field of fire investigation has been slow to evolve from an art to a scientific inquiry.

Some explanations for this state of affairs follows. Fire investigation, for the purpose of preventing future fires, is generally not as interesting to the fire service which is more interested in suppression. Fire investigation, for the purpose of arson detection, is also shunned by the fire service as it is viewed as a law enforcement responsibility. On the other hand, much of the law enforcement community viewed this function as the exclusive province of fire department personnel, as it was generally believed that one could not acquire the skills necessary to conduct a fire investigation without years of experience fighting fires. These problems are compounded by the volunteer nature of the fire service in many areas of the country. In such organizations funds for fire investigation and training are scarce to nonexistent.

Until a couple of decades ago, fire cause determinations were made on an a priority basis—where the belief that the underlying causes for observed effects were already known (Noon 1995)—and investigators were trained in the art of fire investigation. Richard Custer (1992) (one of our presenters today) aptly points out that in the past, "In many cases, practice of the art has outweighed the science due to lack of detailed and scientific understanding of fire behavior."

During the last decade or so, more emphasis has been placed on the scientific and technical aspects

of fire investigation. Cooke and Ide (1992) note that "the science of fire investigation is undergoing a period of rapid expansion and what might be termed an information explosion. Many beliefs commonly accepted in the past have now been superseded ...."

One of the single most significant events in the transition from an art to a science has been the publication by the National Fire Protection Association (NFPA) of *NFPA 921: Guide to Fire and Explosion Investigations* (NFPA 1995). The authors advocate relating fire investigation to the scientific method and have questioned a number of long-standing rules of thumb and theories which were used in making fire cause determinations by incorporating new knowledge of fire behavior gained through research (primarily conducted by the Center for Fire Research).

As a result, many observations of fire damage formerly believed to be positive proof of a particular cause may now have more than one explanation. Custer (1992) notes that "In some respects, then, the advances in the understanding of fire have made investigations more difficult rather than easier," and "In the end, fires that we would have been sure of in the past may now have to be 'undetermined'."

It is hoped that this paper will help criminalists to gain a better understanding of the technical aspects of fire/arson investigation as seen by the field investigator and entice them to get out to fire scenes where they can complement the fire and arson investigation team. Furthermore, we hope that the sharing of knowledge through this symposium will not only provide a forum for the discussion of new techniques and issues relevant to arson evidence, but will also help to foster (where it does not already exist) and strengthen (where it does) a symbiotic relationship among the diverse set of investigators and criminalists responsible for identifying, collecting, preserving, documenting, and analyzing arson evidence.

METHODOLOGY

For many years the study of fire/arson investigation was largely ignored. During the 1960s and early 1970s, America began to experience a dramatic increase in incendiary fire conduct. Many areas within our cities were being compared to the aftermath of World War II. Consequently many textbooks, handbooks, and other manuals began to appear. Only a few of the texts were perceived as authoritative sources; peer-reviewed professional and scholarly journals dedicated to the subject of fire and arson investigation did not exist. Peer-review journals like *Fire Technology* (a publication of the NFPA) and *Journal of Forensic Sciences* (a publication of the American Academy of Forensic Sciences) have published only a few articles on fire investigation. Most of the texts were written by field investigators (with backgrounds in the fire service or law enforcement), forensic scientists, or engineers. A handful were authored by noteworthy public and private organizations such as the Federal Emergency Management Agency's National Fire Academy (NFA), NFPA, International Fire Service Training Association (IFSTA), the Center for Fire Research of the National Bureau of Standards or NBS (now known as the National Institute for Testing and Standards), the Investigations Institute of the National Association of Fire Investigators (NAFI), and the Institute of Fire Engineers. Also while many newsletters and periodicals have come and gone, the *Fire and Arson Investigator*, which is the official publication for the International Association of Arson Investigators (IAAI), has been consistently published since 1949.

For the most part, the texts used for this research make up the main body of literature for the field of fire and arson investigation. Perhaps the greatest problem with the literature is that much of it is not supported by science. Nonetheless, this is the body of knowledge as it existed and from which most investigators relied on to learn their trade.

The literature review was conducted by searching for key words in the index and table of contents of the texts.

EFFECTS OF FLASHOVER

Our first topic of discussion is flashover. The questions addressed in this section are as follows: What is flashover? Why is flashover important in the discussion of arson evidence? What are its effects? How did our ignorance, lack of understanding, or misunderstanding of this process affect fire investigations? and How has information offered in the literature evolved since the 1960s?

What is flashover? Today we know that when fire in a room or other compartment continues to grow beyond its incipient stage and gases descending from the ceiling level approach 1100°F, target fuels (all combustible materials) in the room pyrolyze and ignite as a result of radiant heat transferred from the ceiling gases (or flames if flameover occurred) to the

materials below. This causes full-room involvement, extreme temperature, and severe damage if burning continues (NFPA 1995).

Why is flashover important in the discussion of arson evidence? The occurrence of flashover, our first topic of discussion, may be an indication of arson if the fuel load said to have been present was not capable of producing flashover conditions in the time it actually occurred. However, the purpose of discussing flashover here is to better understand how our ignorance of this process led investigators to misinterpret burn patterns and to arrive at false conclusions about the presence of flammable liquids.

What are its effects? *NFPA 921: Guide for Fire and Explosion Investigations* (NFPA 1995), which is considered by many to be today's industry standard, advises investigators that flashover may be responsible for the rapid spread of fire as well as low-wall burn and floor-burn patterns, which in the past were seen as indicators of arson. Regarding the rapid spread of fire, NFPA 921 states:

> "Investigators may form an opinion that the spread of fire growth or the extent of damage was greater than it would be expected for the normal fuels believed to be present and the building configuration. These opinions are subjective, however, as fire growth and damage are related to a large number of variables and the assumptions made by the investigator are based on that investigator's individual training and experience ... What an investigator may consider as excessive, unnatural, or abnormal can actually occur in an accidental fire."

In fact "Research has shown that time to flashover from open flame can be as short as 1 and 1/2 minutes."

How did our ignorance, lack of understanding, or misunderstanding of this process affect fire investigations? Prior to our understanding of flashover, it was common knowledge among investigators that an accelerant would have to be used to bring a fire to full-room involvement in a matter of minutes, or that burns on walls which reached floor level were also the result of accelerant use. As a result, many conclusions about the cause of fires were incorrect. As we began to better understand flashover, many of the past assumptions became invalid.

How has information offered in the literature evolved since the 1960s? One of the early texts on fire investigation which was considered an industry standard at the time, was Kirk's text *Fire Investigation* (Kirk 1969). It is interesting to note that the term flashover does not appear in this text. Neither is it mentioned in the texts which immediately followed it—*Accidental or Incendiary* (Fitch and Porter 1975); *Arson: A Handbook of Detection and Investigation* (Battle and Weston 1975); and *Elements of Arson Investigation* (Huron 1976). In 1977 the first text to introduce flashover was *Fire-Arson Explosion Investigation* (Kennedy 1977). The author defines flashover as "the almost instantaneous flash which occurs as flammable liquids of fibrous or fuzzy materials, such as upholstered furniture, ignite across their entire surface when sufficient heat is applied" (Kennedy 1977). The author goes on the explain a flashover characteristic which he states is "closely related to room temperatures" and that "Observations of test fires show that furniture ignites without direct flame contact between 400°F and 500°F, but when room temperatures reach the vicinities of 600°F to 700°F a flashover may occur and the entire room may appear to burst into flames at once." While it is clear that this description of flashover is somewhat inaccurate, it is, however, the first text which introduces this phenomenon.

Elements of Fire and Arson Investigation (Bates 1977) and *Arson Investigation* (Carter 1978), two texts following Kennedy's which fail to mention flashover.

In the *Anatomy of Arson* (French 1979) the author writes about a flashover point. He states, "If the fire continues, it may eventually reach a stage where all exposed combustible surfaces simultaneously burst into flames." His use of the word eventually makes it clear that it was not understood that flashover may actually occur in a very short time. Hence, the rapid spread of fire was still considered indicative of the use of an accelerant and not a result of normal fire behavior.

In *Physical and Technical Aspects of Fire and Arson Investigation*, Carrol confuses flashover with flameover. He states, "Since there is little difference between the temperatures along the ceiling from one end of the room to the other, the entire ceiling will appear to burst into flames simultaneously, although it usually happens that the area closest to the source of heat will ignite first and very rapidly involve the entire ceiling, working to the extreme end of the room in a matter of seconds" (Carrol 1983).

The NFPA published an *Instructor's Manual for Origin and Cause Determination* (NFPA 1979) which

advises the investigator to suspect the use of a flammable liquid if the fire spread was "abnormal" or "if extensive burning is discovered on the floor." Again, the rapid development of fire and floor burns (both effects of flashover) were not yet understood and the investigator was misled.

Dennet (1980) confuses flashover with backdraft. He describes flashover as follows: "Briefly, flashover is a term used to describe what happens when the temperatures of the contents of a room or building are raised to the ignition temperatures, but do not ignite because of an oxygen deficiency. When the room or building is ventilated, the inrush of air allows all of the contents to ignite simultaneously, sometimes with explosive force."

The *Fire Investigation Handbook* (NBS 1980) describes flashover as occurring when ceiling temperatures reach 932°F to 1112°F and cautions the investigator not to be misled into believing multiple fire origins exist, but fails to articulate why. Roblee and McKechnie (1988) authored *The Investigation of Fires* and they also described flameover in their definition of flashover.

The IFSTA handbook *Fire Cause Determination* (1982) also describes flashover, however, with no discussion of the resulting fire patterns or the time it takes to occur.

In 1984 the NFA produced *Fire and Arson Investigation (Instructor's Guide)* (NFA 1984). Here, flashover is properly defined and for the first time investigators are advised that flashover "may cause [an] area to appear to have been exposed to flammable accelerants..."

Kennedy (1985) wrote a new text, *Fires and Explosions: Determining Cause and Origin.* Here the same lacking definition which appeared in his 1977 text is offered for flashover. Cooke and Ide (1992), in their discussion of flashover, advise investigators that flashover can occur within 4 or 5 minutes and that "from this point on, the original burning merges into the secondary burning to present the investigator, after the fire is out, with an evenly burnt room."

In a 1990 fatal fire in Jacksonville, FL, fire/arson investigators arrested a man they believed was responsible for setting the fire. Partly based on their observations of low-wall burns and irregular floor-burn patterns, they alleged that the defendant poured a flammable liquid in the hall and living room and ignited it. When laboratory analyses failed to confirm their hypothesis, the court allowed a test burn of the abandoned house next door to determine if the defense claim that such fire patterns could have been produced as the result of postflashover full-room involvement. In a dramatic experiment led by John Lentini of Applied Technical Services, Inc., and John D. Dehaan of the CA Department of Justice, it was demonstrated that the fire patterns observed in the fatal fire were almost identical to those produced by the test fire which was ignited by a cigarette lighter touched to a couch without the use of flammable liquids. This experiment which was fully documented on video tape (Lentini 1990) is a significant contribution to the body of knowledge concerning flashover.

Dehaan in his text, *Kirk's Fire Investigation* (Dehaan 1990) discusses flashover and warns the investigator, "Remember that if a room subsequently goes to flashover, the radiant heat produced may obliterate some of the more subtle indicators on the floor." He also warns that, "Any area which has a floor burned or a wall right down to the floor should be considered suspicious and deserving of further investigation", but "Such a burn does not mean by itself that the fire was incendiary in origin."

Hobson advises that tests conducted by the NBS have shown that floor temperatures can actually exceed temperatures at the ceiling level when flashover occurs. Therefore "the assumption that the finding of alligatoring at floor level indicates arson is totally wrong" (Hobson 1992).

FIRE PATTERNS

Kirk (1969) and other authors of the time advised investigators that it is the point of origin and source of ignition (at that point) that will lead the investigator to determining the cause of the fire. He first explains some simple rules of fire behavior which are necessary to understand before one can hope to interpret the resulting fire patterns. Fire patterns as defined by NFPA 921 (NFPA 1995) are as follows:

> "... the visible or measurable physical effects that remain after a fire. These include thermal effects on materials, such as charring, oxidation, consumption of combustibles, smoke and soot deposits, distortion, melting, color changes, changes in the character of materials, structural collapse, and other effects."

The investigator is said to read these fire patterns and use them to follow the path of normal

or natural fire behavior and travel that will lead him or her to the point or area of origin.

Unfortunately, as origin and cause determination become more complex and scientifically based, many investigators became more interested in discovering fire patterns that would indicate the use of a flammable liquid, than those indicating the point of origin. These indicators include, but are not limited to: wood char, spalling, low burns and floor burns, crazing of glass, doughnut-shaped patterns, trailer patterns, and alloying of metals. Since a full discussion of these is beyond the intended scope of this paper, only wood char, spalling, and low burns are included.

Wood Char

NFPA 921 (NFPA 1995) advises:

> "The appearance of the char and cracks has been given meaning by the fire investigation community beyond what has been substantiated by controlled experimentation. It has been widely stated that the presence of large shiny blisters (alligator char) is proof that a liquid accelerant was present during the fire. This is a misconception. These types of blisters can be found in many types of fires ..." also "It is sometimes claimed that the surface appearance of the char, such as dullness, shininess, or colors has some relation to the use of a hydrocarbon accelerant. There is no scientific evidence of such a correlation, and the investigator is advised not to claim indications of [an] accelerant on the basis of the appearance of the char alone."

For many years investigators have associated certain types of wood char with the use of a flammable liquid. The first author to write about this correlation is Huron (1976) where he advises investigators that "The application of petroleum products to wood causes a deep burning. Smaller, deeper alligator effects appear [different] than from charring by applied heat only." Similarly Bates (1977) instructs investigators that when searching for evidence of incendiarism they should search for "... unusual wood charring and uneven wood burning." He explains that "The application of [a] petroleum product to wood causes a deep unnatural burning."

Carter, in his text *Arson Investigation* (Carter 1978), is the first to warn investigators that "deep charring ... is not per se indicative of an accelerant." On the other hand, in his capacity as NFPA Chief Fire and Arson Investigation Specialist, where he develops a series of training manuals on fire and arson investigation he offers a slightly different view in *Instructor's Manual for Origin and Cause Determination* (Carter 1979):

> "Arsonists frequently use accelerants to assure quick and total destruction of property. Fortunately for investigators, accelerants create characteristic burn patterns ... Fast-rising heat on exposed wood surfaces may cause alligatoring—deep, rolling grooves and shiny, smooth blisters."

The same year French (1979) offers this caveat:

> "Due to limited scientific experimental study on these particular phenomena in relation to wood and fire, there is no present reliable data tending to identify the size of the alligatoring (its coarseness or fineness), its gloss, or other visual appearance with either rapid temperature rise or with the presence or use of flammable accelerants such as gasoline, acetone, thinner, or other volatile liquids or other incendiary materials."

The NBS reported in their *Fire Investigation Handbook* (NBS 1980) that "Fast fires produce hump-backed, shiny alligatoring." While they do not specifically link accelerants to shiny alligatoring, many investigators made that assumption since they were taught that fast burning was the equivalent of flammable liquid use.

Ignoring the warning in French (1979) IFSTA, in the strongest statement up to this time, notes in their publication *Fire Cause Determination* (IFSTA 1982), "Generally, alligatoring is smaller the closer one gets to the point of origin if the fire developed normally. If the alligatoring is large, deep and shiny, the fire spread extremely rapidly. Large alligatoring should be considered an indication of the nearby presence of a flammable or combustible liquid."

Even the NFA in its document *Fire and Arson Investigation (Instructor Guide)* (NFA 1984), reported that alligator char (large rolling char pattern) may indicate the use of flammable accelerants ... [and]

alligator char may have a shiny appearance from [the] effect[s] of flammable accelerants."

Spalling

Spalling, as used in fire investigation, is defined as "... the breakdown in surface tensile strength of concrete, masonry, or brick caused by exposure to high temperatures and rates of heating resulting in mechanical forces within the material" (NFPA 1995). This is another fire pattern thought to be related to flammable liquid accelerant use.

According to NFPA 921 (NFPA 1995) "the use of spalling evidence is one of the most misunderstood and improperly used evidential elements. Among the misconceptions is that spalling is caused only by the presence of a liquid accelerant." The authors advise that spalling can be the result of exposure to any high rate of heating or the rapid cooling of a heated mass of concrete.

As an illustration of how a misunderstanding of flammable liquids and spalling influenced a fire investigator's opinion, the following is offered. In a fairly recent arson trial where the author consulted for the defense, it was the prosecution's expert (a municipal fire investigator) who hypothesized that a flammable or combustible liquid poured on the concrete floor caused it to spall and collapse into the first floor. Here is a portion of his Grand Jury testimony:

> "What happens, including lubricating oil, the oil or liquid itself actually burns. As the liquid is heated, it vaporizes. The liquid is the cool part. It is isolated. The puddle starts to shrink and the outer perimeter of the puddle is tinged with fire. As for the vaporizing, [as] the puddle gets smaller, the more area of the floor is attacked by the fire. In this case it was a cement floor. With cement, when it is heated with a flammable liquid, there is as pocket of gas and moisture still in the cement. As it is heated with the fire, these pockets started to expand and started to bust. The little pockets that are heated inside the cement, sort of like exploded and popped off. That is why I asked him if there were any flammable liquids. The floor was heated, that is how it collapsed."

Aside from the fact that the investigator apparently did not conduct a thorough examination of the collapsed structure (since it became evident during trial that the floor was constructed of wood, not concrete), his misconception of flammable liquids and spalling caused him to determine that the fire was incendiary even in the absence of any confirmation of a flammable liquid residue.

Regarding the literature, no mention is made of spalling by Kirk (1969) and again Kennedy (1977) is in the forefront introducing the investigator to spalling. Here spalling is defined as "the breakdown in tensile strength of concrete [and] of brick, usually accompanied by color change. Spalling is caused by the application of heat in high temperature ranges to concrete, brick, stone, or mortar." The problem with this definition is that it refers to "the breakdown in tensile strength" and does not specify surface tensile strength leading the readers to draw their own conclusions on the severity of the breakdown (as illustrated in the above example). The author also incorrectly advises that such high temperatures may be a result of exposure to the 3000°F burning temperature of accelerants and not the lower burning temperatures of wood (1000°F to 1200°F). While accelerants may cause spalling due to their high-heat release rate, it should be noted that the flame temperatures are essentially the same for flammable liquids as they are for wood (NFPA 1995).

The NFA (1984) also advises that spalling "May indicate possible use of accelerants." In Kennedy (1985) previous errors are corrected, and the author warns that spalling may be caused by burning materials other than flammable liquids.

In Hobson (1992) the author writes that, "In the past, the accepted thoughts were that spalling was an indication of an accelerant. As we can see, this is definitely not true." He goes on to explain that the main source of spalling is moisture trapped in the concrete which expands as it turns into steam as heat is applied.

Noon (1995) offers an engineering perspective and tells us that, "If an accelerant has been poured on a concrete floor and ignited, it sometimes causes spalling ..." and "... if heat transfer between the burning flammable liquid and the concrete slab is poor, it is likely that no spalling will occur."

Low Burns and Floor Burns

In the past, if the burns on a wall reached down to the floor level or got under a door, furniture, or

baseboard, or caused a pool-shaped or irregular-shaped burn pattern on the floor, or a hole in the carpeting or floor, they were considered to be indicative of the presence of a flammable liquid.

Today we know that there are other explanations for such patterns. NFPA 921 (NFPA 1995) advises us that if postflashover full-room involvement is reached, "damage can include charring of the undersides of furniture, burning of carpet under furniture, uniform burning around table legs, burning of baseboards and undersides of doors, and burning on floor covering in corners ... [and] Holes can be burned through carpet and floors." The guide cautions that in "any situation where the presence of flammable liquid is suggested, the effects of flashover, airflow, hot gases, melted plastics, and building collapse must be eliminated."

Back in 1969 although Kirk was cautious about associating low burns and floor burns with liquid accelerants, he does advise, "When the burn is even with the floor surface, it is highly probable that a liquid was used, since other sources of intense local combustion, such as trash, rarely if ever burn right to the floor" (Kirk 1969).

Although Carter (1978) warns the investigator that "... a complete burnthrough of the flooring is not per se indicative of an accelerant," he also writes on the same page (page 84) in a caption under a photograph that "Holes in the floor such as these are indications of the use of an accelerant." Further, he states that "a wood door charred on the bottom edge is a strong indication that an accelerant burned on the floor under the door" and that "low burning around the baseboard indicates the presence of a flammable liquid."

In the NFPA's publication *Instructor's Manual for Origin and Cause Determination* (NFPA 1979) Carter advises, "Suspect the use of a flammable liquid if ... extensive burning is discovered on the floor, in room corners, and on the bottom surfaces of doors located in the area of origin." Carroll (1983) concurs and asks investigators to "check the bottom edges of doors and note any severe charring there ... [because] Normally, the bottom edge of a door will be uncharred during a structural fire; damage to this portion of the door will indicate an unnatural condition." IFSTA's *Fire Cause Determination* (IFSTA 1982) depicts a photograph of a floor burn pattern (Figure 6-14) and captions it as follows: "The irregular and deep char damage clearly indicates the use of a flammable liquid on this hardwood floor." They also warn that "low levels of charring are good indicators of [a] flammable liquid being used."

The NFA in *Fire and Arson Investigation* (NFA 1984) is the first source to alert investigators that "extensive floor damage may indicate the use of flammable accelerants or flashover of the floor area."

In 1992 Hobson and NFPA 921 acknowledge that the floor burn pattern is one of the most misinterpreted. Hobson admonishes that "Far too many fire investigators, specifically those still involved in the old firemen's tales school of thought, immediately upon seeing a floor burn pattern, conjure up the fact that it is a pour pattern resulting from a liquid accelerant." He goes on to say that, "To further compound this error, they take a sample from the burn area and ship it off to the laboratory without a control sample." Hobson does not stop there and vents a bit more regarding the misinterpretation of a hole burned in a floor. Here he argues, "Another problem we have with these people and their old firemen's tales is their concept that holes are burned in floors by either flammable or combustible liquids" (Hobson 1992)

ACCELERANT DETECTION

While rapid/unnatural fire spread and fire patterns discussed above, led investigators to believe a flammable liquid was used to accelerate a fire, the literature has also instructed in the field detection of such materials. Kirk (1969) advised that "The primary test is to smell all suspicious areas, since many flammable liquids have odors which are detectable and often characteristic." He also warns that since what is smelled is evaporating liquids, the "only very effective time to smell such odors is immediately following the fire." Kirk also instructs to scoop up soil which may contain flammable liquids and place them in water and to look for a floating film which will show interference colors. This, he says, is exceptionally sound ground for the suspicion that flammable liquids are present and calls for samples for laboratory analysis. Finally, Kirk suggests using a vapor detector, immediately after entering the scene to collect samples for laboratory examination.

Battle and Weston (1975) advise investigators to learn to recognize the odors of various flammable liquids by placing small amounts in wide-mouth glass jars and sniffing them with their eyes closed. Where large amounts of water were used to extinguish the fire and odors are not readily distinguishable, Huron (1976) advises to place pieces of charred wood from suspected area into a wide-mouth glass container, heat it in water (60°C to 70°C), open container, and smell. He further states that "the appearance of soot is highly characteristic for different flammable liquids

and it is recommended that the investigator experiment with smoke and soot to familiarize himself with its appearance."

Carter (1978) advocates taking samples where odors of flammable liquids are detected, however, warns investigators that "The practice of rubbing one's hand along a smooth surface and then sniffing the fingers is utterly ridiculous and completely nonproductive, for flammable liquids poured on the floor and ignited would burn completely on the flat surfaces."

In recent years, textbooks have not had much new to say about the detection of flammable liquid accelerants at the scene. Articles about the use of canines in this effort have appeared and stirred up quite a bit of controversy. Several articles describing the usefulness of canines to detect hydrocarbon accelerants have appeared in the *Fire and Arson Investigator* during the past few years. The controversy arose, however, when investigators began testifying that they were certain accelerants were present based on their observations and the dogs' findings despite negative results from the laboratory. Such testimony was disturbing to the scientific community primarily since dogs lack the ability to discriminate between pyrolysis products and accelerants.

In September 1994, the Forensic Science Committee of the IAAI reported in the *Fire and Arson Investigator* that "any alert or indication not confirmed by laboratory analysis must be considered a false positive or unconfirmed indication for the purposes of origin and cause determination." Its position on the role of the canine is that they "... assist the fire investigator in the selection of samples for subsequent laboratory analysis and to provide a preliminary indication of the presence of an ignitable liquid."

CONCLUSION

In conclusion it should be clear that the field of fire investigation has and continues to suffer from growing pains. Misinformation has abounded, the body of scientific knowledge has been slow to evolve, and the lack of training has contributed to the misapplication of what was scientifically known.

Why is it so important that fire and arson investigations be improved? Consider the following: In many respects, the role of the fire investigator and the medical examiner (or pathologist) are similar. Both are responsible for conducting an investigation which seeks to learn the cause of an event and determine if that event was criminal in nature. Both are allowed to offer their opinions as to cause when recognized by the court as expert witnesses. In both cases the opinions of the investigators may prove extremely important and may significantly affect the parties involved. In a civil case their testimony could mean the difference between an award of millions of dollars or no compensation at all. In a criminal case it could mean freedom, incarceration, or even execution (in capital cases). The major differences between these roles arises when one considers the body of knowledge in the respective fields and the training and education of the investigators. In most parts of our country, pathologists have extensive formal education and have earned medical degrees. Their opinions are most likely based on scientific investigation based on a sound body of medical science. On the other hand, fire investigators on the average have little formal education in the sciences and are forming opinions without a sound body of scientific knowledge. They are often accused of depending on firemen's tales as the basis for their opinions, however, it appears that we are slow to acknowledge that many of these tales either originated or were supported in the body of literature (from some fairly authoritative sources). In any event, one can only wonder how many people were adversely affected as a result of our lack of understanding of fire behavior.

Where then do we go from here? Since it appears that the field of fire and arson investigation is at the dawn of a new era, I propose that we concentrate our efforts on creating a true profession. Many who are working in the field would contend that fire and arson investigation is a profession; others would strongly disagree. A profession has hallmarks such as: the attainment of a postsecondary educational degree; professional organizations which set standards and encourage compliance with them; provide a forum for members to meet, exchange ideas and information, and to encourage scientific inquiry; and the publication of professional peer-reviewed journals which would house the body of scientific knowledge developed. While some of the hallmarks above are in place, others are clearly lacking.

Those who are in leadership positions in the field of fire and arson investigation share in the responsibility to professionalize this field. The challenge to them is as follows:

- Encourage the NFPA in cooperation with other interested organizations to develop a standard for a science-based college

curriculum for fire investigation which would be incorporated into its current Standard for Professional Qualifications for Fire Investigators (NFPA 1033).

- Encourage states to pass legislation which would require regulation in the form of certification and licensing of those who engage in fire investigations. Qualifications for certification and licensing should include the successful completion of college credits listed in the above-recommended standard, written examinations and practical examinations, and continuing education credits.

- Encourage organizations which are dedicated to fire and arson investigation (such as the IAAI and NAFI) to adopt a more scholarly approach whereby they would issue a call for papers and hold annual meetings where research findings and new knowledge and information is presented and shared in the form of papers, plenary session speakers, and posters. In addition, encourage them to develop a profession scientific journal which would accept articles for publication via peer review and actively market its publications to college and university libraries (nationally and internationally).

- Encourage the development of an Academy of Fire and Arson Investigation which would be affiliated with a major university and would hold annual meetings and publish a scholarly peer-reviewed journal.

- Encourage governmental agencies and private organizations to conduct fire research and to develop grant programs.

- Encourage governmental crime laboratories to offer specialized training in fire and arson investigation and to have selected criminalists respond to major fires where they would join the investigative team. This would add the much needed scientific perspective to the investigation.

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Occupational Safety and Health Issues for Arson Investigators

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The Occupational Safety and Health Act[1] (the Act) has some important implications for the job safety and health of arson investigators. It sets forth responsibilities for most of the organizations employing investigators and for investigators themselves. Standards[2] issued by the Occupational Safety and Health Administration (OSHA), an agency of the Department of Labor formed as a result of the Act, establish safety and health requirements which impact on arson investigators. In addition, OSHA recognizes that important safety and health information is often presented by industry standards, consensus standards, and other recommended practices. A number of safety and health provisions important to arson investigators have been included in the recent revision of the National Fire Protection Association (NFPA) *Guide for Fire and Explosion Investigations*, NFPA 921 - 1995.[3] The new revision incorporates safety provisions from the *Manual for the Determination of Electrical Fire Causes*, NFPA 907M - 1988.[4] This paper reviews and summarizes a number of these requirements, standards, and recommendations.

SAFETY AND HEALTH COVERAGE FOR ARSON INVESTIGATORS

The Act has some important implications for the job safety and health of arson investigators. It defines employer and employee responsibilities and rights with respect to workplace safety and health. Briefly, section 5 of the Act requires employers to protect employees from recognized hazards likely to cause death or serious harm and to comply with mandatory standards. Also, section 17 indicates that a serious violation is deemed to exist where there is substantial probability that death or serious physical harm could result unless the employer did not or could not, with the exercise of reasonable diligence, know about it. Employees are required to comply with respect to their own actions and conduct.

OSHA was set up to develop and enforce job safety and health standards. The Act directs the focus of OSHA enforcement activity toward employers. This is explained in detail in the Act itself and OSHA Publication No. 2056 - *All About OSHA*.[5] Generally, the Act requires that arson investigators and their employees be reasonably diligent regarding safety and health requirements. Arson investigators are found working for private companies and federal, state, and local governments. The Act applies to employment in commerce (*i.e.*, employees of private companies). Work activities covered by other federal job safety and health regulations are excluded, for example, those covered by the Department of Transportation (DOT) regulations. Private business activities have almost always been found to be in commerce and covered by the Act. The individual work of self-employed persons is not covered.

Government employees are covered differently. The work of federal employees is generally covered by section 19 of the Act. This section requires effective and comprehensive programs to protect federal employees. Regulations established to put this requirement into effect[6] apply to most federal employees. The principal exception is *uniquely military* activities of the armed forces. Other activities, for example, arson investigations by civilian investigators employed by a military service, are covered.

State and local government employees in the 25 states and territories that have adopted OSHA-approved occupational safety and health plans must be protected by a program which is at least as effective

as the OSHA program. There is no coverage by the Act for employees in states which have not adopted approved state plans, but several of these states have adopted their own programs. For example, Illinois has adopted OSHA standards for state and local government employees as state regulations.[7] Where working activities are not covered by OSHA standards, OSHA standards as well as consensus and other recognized standards indicate patterns for reasonable conduct.

OSHA STANDARDS

Standards issued by OSHA establish safety and health requirements which impact on arson investigators. The sections on personal protective equipment, emergency response, electrical safety-related work practices, and bloodborne pathogens frequently apply to fire and explosion investigation work. Depending on the nature of the work performed, various other standards may apply as well.

The OSHA standard on personal protective equipment, 29 CFR 1910.132 through 1910.138,[8] has been recently revised. Briefly, employers are required to provide and require use of appropriate protective equipment made necessary by hazardous conditions. The standard requires employers to determine if hazards are present or are likely to be present. The selection of safe, appropriate equipment and training is required. Effective performance standards for eye and face protection equipment; respirators; and head, foot, and hand protection are established. Written certification of the hazard assessment and training must be prepared by the employer.

When self-contained breathing apparatus or other respiratory protective equipment is to be used by investigators, 29 CFR 1910.134,[9] the OSHA respiratory protection standard applies. Employers are required to implement a minimal acceptable program including the following:

- Written standard operating procedures for selection and proper use of approved respiratory protection equipment;
- Hazard assessment and continued surveillance of hazards in the work area;
- Inspection and evaluation of the program;
- Instruction, training, and fit testing;
- Cleaning and disinfection;
- Proper storage and inspection; and,
- Appropriate medical determination of the health status and physical ability of the investigators to use respirators.

It is frequently recommended that investigators wear protective gear including protection for the head, eyes and face, body, hands, and feet at incident sites.[10] Investigations of emergency sites where there is exposure to flammable substances require the use of appropriate fire-retardant clothing. Where falling or rolling objects are present or objects may pierce the sole, suitable foot protection is necessary.

The standard on emergency response to hazardous substance releases, 29 CFR 1910.120(q),[11] lays out performance-based requirements for safety and health planning, organization, incident command, protective gear, training, and other safe practices necessary for emergency response at sites where an uncontrolled release of a hazardous substance has occurred or is likely to occur. Where investigators participate in on-scene activities, they must comply with requirements of the emergency response standard at the level of their participation. Frequently, the knowledge, skills, and training required for first responder awareness and operations level is the minimum necessary for on-scene investigation activities.

The section dealing with specialist employees is also frequently applied to investigation work.

> "Employees who, in the course of their regular job duties, work with and are trained in the hazards of hazardous substances, and who will be called upon to provide technical advice or assistance at a hazardous release incident to the individual in charge, shall receive training or demonstrate competency in their area of specialization annually."[12]

Appendix C in 29 CFR 1910.120 indicates that the training of specialist employees is to include "the care and use of personal protective equipment including respirators; knowledge of the incident command system and how they relate to it ..."[13] This section is specifically intended to prevent dangerous "free lance" or "lone wolf" activities during an emergency.

The text of the 29 CFR 1910.120 training requirements for first responders and a related guidance on training curricula are reprinted at the end of this paper.

Briefly, the electrical safety-related work practices standards 29 CFR 1910.331 through 1910.335[14] require that investigators be properly trained and qualified to perform their work where electrical hazards may be present. Where energized parts and conductors are not guarded, investigators must be protected through the use of effective electrical personal protective equipment, insulating barriers, or by de-energizing the hazardous equipment and locking or tagging out.

The OSHA standard on bloodborne pathogens, 29 CFR 1910.1030,[15] applies where there is occupational exposure to blood and other potentially infectious materials. Investigators who assist at incidents where blood, body fluids, and/or contaminated equipment items are present, where there have been traumatic injuries, or who assist in handling human remains or body parts are potentially exposed to infection. Occupational exposure is defined as "reasonably anticipated skin, eye, mucous membrane, or parental contact with blood or other potentially infectious materials that may result from the performance of an employee's duties."[16]

"It is the responsibility of employers of emergency responders to ensure that their employees are properly informed and adequately protected at the work site and in emergency situations."[17] Briefly, where exposure is reasonably anticipated, the standard mandates a comprehensive program involving the following activities:

- Exposure determination;
- Exposure control plan;
- Communication of the hazards to employees;
- Hepatitis-B vaccination availability;
- Universal precautions methods;
- Engineering and work practice controls;
- Personal protective equipment;
- Housekeeping;
- Labeling;
- Postexposure evaluation and follow-up; and,
- Record keeping.

INDUSTRY STANDARDS, CONSENSUS STANDARDS, AND RECOMMENDED PRACTICES

OSHA recognizes that important safety and health information is often presented by industry standards, consensus standards, and other recommended practices.[18] Generally, when OSHA investigates an employer, the investigation and subsequent activities are civil proceedings. (Criminal cases are referred for investigation by the Department of Justice with OSHA providing technical assistance. Criminal cases most frequently involve situations where a willful violation of an OSHA standard caused the death of an employee.) In a very large proportion of cases, employers do not contest OSHA citations. When they do contest, proceedings are conducted before the Occupational Safety and Health Review Commission and the federal courts. To prove a violation of a standard, the agency initially must show the following:

> "that the cited standard applies, that its terms were not complied with, that employees had access to the violative conditions, and that the employer knew or with reasonable diligence, could have known of the violative conditions."[19]

Showing that the terms of the standard were violated generally also involves showing that the conditions were hazardous or unreasonably hazardous at the site in question. In addition, establishing what was not reasonably diligent about an employer's behavior is often a critical part of the case. An employer may demonstrate compliance (show reasonable diligence) by effective safety and health programs dealing with the hazard. Even if there is a violation of the details of an OSHA standard, agency procedures indicated that no citation is to be issued when one of the following circumstances exists:

- "An employer complies with the clear intent of the standard, but deviates from its particular requirements in a manner that has no direct or immediate relationship to employee safety or health ...
- An employer complies with a proposed standard or amendment or a consensus standard rather than with the standard in

effect at the time of the inspection and employer's action clearly provides equal or greater employee protection or the employer complies with a written interpretation issued by ... OSHA ...

- An employer's workplace is state of the art which is technically beyond the requirements of the applicable standard and provides equivalent or more effective safety or health protection."[20]

Demonstrating compliance with the safety and health aspects of an industry guideline such as the *Guide for Fire and Explosion Investigations*, NFPA 921 - 1995, could therefore be important in showing reasonable diligence regarding safety and health for arson investigators.

NFPA 921

A number of safety and health provisions important to arson investigators have been included in the recent revision of the Guide for Fire and Explosion Investigations, NFPA 921 - 1995. The actual text of the guide related to safety precautions should be reviewed for details and context. The following outline is a summary of Chapter 10 on safety.

10-1 General

- Fire scenes are dangerous.
- Due caution must be exercised.

10-1.1 Investigating the Scene Alone

- Do not work alone.
- Another individual must be available to summon help.
- Tell a responsible person when you will be back.

10-1.2 Safety Clothing and Equipment

- Appropriate equipment is necessary, including:
  - Shoes, boots, gloves, helmets;
  - Safety clothing—coveralls or turnout gear;
  - Safety glasses or goggles;
  - SCBA's;
  - Life lines, nets, ladders; and,
  - Hazardous environment suits.
- Proper training in the use of gear is required.

10-1.3 Fire Scene Hazards

- Keep alert.
- Fight complacency and risk taking.
- Structural stability may not be known.

10-1.4 Personal Health and Safety

- Be aware of chemical, biological, radiological, and other potential hazards.
- Special precautions may be needed:
  - Rubber gloves;
  - SCBA's; and,
  - HAZMAT suits.

10-1.5 Investigator Fatigue

- Work is long and hard.
- Some hazardous effects may occur:
  - Decline in hazard recognition skills; and
  - Strength and coordination are reduced.
- Get proper rest and replace fluids.

10-2 Factors Influencing Scene Safety

- Many potential dangers are present.
- Safety precautions and awareness required.

10-2.1 Status of Suppression

- ICS rules, permission for entry, and coordination of activities are necessary.
- Never enter a burning structure unaccompanied by suppression personnel.

- Be alert for burning or rekindling.

- Know the best escape route.

10-2.2 Structural Stability

- Fires/explosions weaken structural components.

- Debris removal may result in further weakening.

- Assess the situation and, if needed, get expert help.

- Demolition or shoring may be needed.

- Hazards may not be apparent:

  - Hidden, perhaps flooded, holes;

  - Weight of pooled water, rain, snow, ice; and,

  - Loose or ice-supported debris.

10-2.3 Utilities

- Charged fuel or water lines may result in a release.

- Know status of the electrical system.

10-2.4 Electrical Hazards

- There is a risk of serious injury or death.

- The biggest risk is immediately following the fire.

- Before beginning the investigation, be certain the power is off or has been disconnected by the local utility company.

- The local utility company is to shut off the power, not the investigators.

- Electrical hazards may be present long after the incident.

- Use a good tagout procedure for the electrical power.

- Personally verify that the power is off.

- Assume that electrical danger is present.

- Do not hesitate to call the utility for verification.

- Regarding electrical safety:

  - Consider all wires to be energized even when the meter has been removed;

  - Be alert for fallen electrical wires in contact with conductors;

  - Look our for electrical contact with TV antennas, metal siding, wiring;

  - Electric lines do not mix well with ladders and elevating equipment;

  - Building power short circuiting can cause arc blast;

  - Rubber footwear is not an insulator;

  - Do not enter a flooded basement if power is on. Never manually switch off the power while standing in water;

  - Do not operate a switch where flammable gases or vapors might be present, shut off the power at a remote point;

  - Power company personnel are able to assist;

  - Digging does not mix very well with underground power lines;

  - There are many possible power sources at a scene;

  - Always use instruments to be sure the power is off.

10-2.5 Standing Water

- Puddles and energized wires can be lethal.

- Water may conceal an impalement or drowning hazard.

10-2.6 Safety of Bystanders

- Rope off and/or post.

- Guard personnel may be necessary.

- Identification and control unauthorized entrants.

10-2.7 Safety of the Fire Scene Atmosphere

- Fires and explosions produce toxic gases.
- Homes, commercial sites, and business sites all contain hazardous materials.
- Asbestos may be present.
- Some areas may be oxygen deficient.
- Ignition sources must be controlled if there are ignitable gases, vapor, or liquid.
- Test for contaminants.

The guideline is one of several documents providing helpful information regarding arson investigation safety. The *Standard of Professional Qualifications for Fire Investigators,* NFPA 1033-1993,[21] indicates that investigators are to meet the requirements of First Responder Awareness and Operations Levels of the *Standard for Professional Competence of Responders to Hazardous Materials Incidents,* NFPA 472 -1993.[22] In addition, many of the competence prerequisites listed in these standards are directly related to the preservation of safety and health. NFPA 1033 refers investigators to the safety chapter of NFPA 921 (reviewed in the outline above) for guidance on safety. Both qualifications and competence documents specify lists of knowledge elements necessary for effective, safe arson investigation activities. This reflects the fact that investigators are frequently present at incident sites where a hazardous material release has or could occur.

APPENDIX C - 29 CFR 1910.120

Emergency Response to Hazardous Substance Releases

29 CFR 1910.129(q) ...

(6)Training.

Training shall be based on the duties and function to be performed by each responder of an emergency response organization. The skill and knowledge levels required for all new responders, those hired after the effective date of this standard, shall be conveyed to them through training before they are permitted to take part in actual emergency operations on an incident. Employees who participate, or are expected to participate, in emergency response shall be given training in accordance with the following paragraphs:

(i) First responder awareness level.

First responders at the awareness level are individuals who are likely to witness or discover a hazardous substance release and who have been trained to initiate an emergency response sequence by notifying the authorities of the release. First responders at the awareness level shall have sufficient training or have had sufficient experience to objectively demonstrate competency in the following areas:

(A) An understanding of what hazardous substances are, and the risks associated with them in an incident.

(B) An understanding of the potential outcomes associated with an emergency created when hazardous substances are present.

(C) The ability to recognize the presence of hazardous substances in an emergency.

(D) The ability to identify the hazardous substances, if possible.

(E) An understanding of the role of the first responder awareness individual in the employer's emergency response plan including site security and control and the DOT *Emergency Response Guidebook* (ERG).

(F) The ability to realize the need for additional resources, and to make appropriate notifications to the communication center.

(ii) First responder operations level.

First responders at the operations level are individuals who respond to releases or potential releases of hazardous substances as part of the initial response to the site for the purpose of protecting

nearby persons, property, or the environment from the effects of the release. They are trained to respond in a defensive fashion without actually trying to stop the release. Their function is to contain the release from a safe distance, keep it from spreading, and prevent exposures. First responders at the operational level shall have received at least 8 hours of training or have had sufficient experience to objectively demonstrate competency in the following areas in addition to those listed for the awareness level and the employer shall so certify:

(A) Knowledge of the basic hazard and risk assessment techniques.

(B) Know how to select and use proper personal protective equipment provided to the first responder operational level.

(C) An understanding of basic hazardous materials terms.

(D) Know how to perform basic control, containment, and/or confinement operations within the capabilities of the resources and personal protective equipment available with their unit.

(E) Know how to implement basic decontamination procedures.

(F) An understanding of the relevant standard operating procedures and termination procedures ...

(8) Refresher training.

(i) Those employees who are trained in accordance with paragraph (q)(6) of this section shall receive annual refresher training of sufficient content and duration to maintain their competencies, or shall demonstrate competency in those areas at least yearly.

(ii) A statement shall be made of the training or competency, and if a statement of competency is made, the employer shall keep a record of the methodology used to demonstrate competency.

Training Curriculum Guidelines (Nonmandatory 1910.120 Appendix E)

C. Emergency response training ...

a. General considerations.

Emergency response organizations are required to consider the topics listed in Section 1910.120(q)(6). Emergency response organizations may use some or all of the following topics to supplement those mandatory topics when developing their response training programs. Many of the topics would require an interaction between the response provider and the individuals responsible for the site where the response would be expected.

(1) Hazard recognition, including:

(A) Nature of hazardous substances present;

(B) Practical applications of hazard recognition, including presentations on biology, chemistry, and physics.

(2) Principles of toxicology, biological monitoring, and risk assessment.

(3) Safe work practices and general site safety.

(4) Engineering controls and hazardous waste operations.

(5) Site safety plans and standard operating procedures.

(6) Decontamination procedures and practices.

(7) Emergency procedures, first aid, and self-rescue.

(8) Safe use of field equipment.

(9) Storage, handling, use, and transportation of hazardous substances.

(10) Use, care, and limitations of personal protective equipment.

(11) Safe sampling techniques.

(12) Rights and responsibilities of employees under OSHA and other realted laws concerning right-to-know, safety and health, compensations, and liability.

(13) Medical monitoring requirements.

(14) Community relations.

b. Suggested criteria for specific courses.

(1) First responder awareness level.

(A) Review of and demonstration of competency in performing the applicable skills of 29 CFR 1910.120(q).

(B) Hands-on experience with the DOT ERG and familiarization with OSHA standard 29 CFR 1910.1201.

(C) Review of the principles and practices for analyzing an incident to determine both the hazardous substances present and the basic hazard and response information for each hazardous substance present.

(D) Review of procedures for implementing actions consistent with the local emergency response plan, the organization's standard operating procedures, and the current edition of DOT ERG including emergency notification procedures and follow-up communications.

(E) Review of the expected hazards including fire and explosions hazards, confined space hazards, electrical hazards, power equipment hazards, motor vehicle hazards, and walking/working surface hazards.

(F) Awareness and knowledge of the competencies for the First Responder at the Awareness Level covered in the NFPA Standard No. 472, *Professional Competence of Responders to Hazardous Materials Incidents*.

(2) First responder operations level.

(A) Review of and demonstration of competency in performing the applicable skills of 29 CFR 1910.120(q).

(B) Hands-on experience with the DOT ERG, manufacturer material safety data sheets, CHEMTREC/CANUTEC, shipper or manufacturer contacts, and other relevant sources of information addressing hazardous substance releases. Familiarization with OSHA Standard 29 CFR 1910.1201.

(C) Review of the principles and practices for analyzing an incident to determine the hazardous substances present, the likely behavior of the hazardous substance and its container, the types of hazardous substance transportation containers and vehicles, the types and selection of the appropriate defensive strategy for containing the release.

(D) Review of procedures for implementing continuing response actions consistent with the local emergency response plan, the organization's standard operating procedures, and the current edition of DOT ERG including extended emergency notification procedures and follow-up communications.

(E) Review of the principles and practice for proper selection and use of personal protective equipment.

(F) Review of the principles and practice of personnel and equipment decontamination.

(G) Review of the expected hazards including fire and explosion hazards, confined-space hazards, electrical hazards, power-equipment hazards, motor-vehicle hazards, and walking/working surface hazards.

(H) Awareness and knowledge of the competencies for the First Responder at the Operations Level covered in the NFPA Standard No. 472, *Professional Competence of Responders to Hazardous Materials Incidents ...*

REFERENCES

[1] Occupational Safety and Health Act, Public Law 91-596, December 29, 1970, as amended by Public Law 101-552, November 5, 1990.

[2] CFR (1994); Code of Federal Regulations; Title 29 CFR 1900 - 1910 (Section 1901.1 to 1910.999) and Title 29 CFR 1900 - 1910 (Section 1910.1000 to End); U. S. Government Printing Office (1994); Superintendent of Documents.

[3] NFPA (1995); *Fire and Explosion Investigation;* NFPA 921, 1995; Quincy, MA; National Fire Protection Association.

[4] NFPA (1988); *Manual for the Determination of Electrical Fire Causes;* NFPA 907M, 1988; Quincy, MA; National Fire Protection Association.

[5] OSHA (1994); *All About OSHA;* U. S. Department of Labor, Occupational Safety, and Health Administration; OSHA Publication No. 2056.

[6] Executive Order 12196 and 29 CFR 1960; See CFR (1994); Code of Federal Regulations; Title 29 CFR 1927 to End; U. S. Government Printing Office (1994); Superintendent of Documents.

[7] 56 Ill. Adm. Code 350 authorized by the Illinois Safety Inspection and Education Act, 820 ILCS 220; and the Illinois Health and Safety Act, 820 ILCS 225.

[8] See reference 2.

[9] See reference 2.

[10] See section 4.6 Field Investigation Tools/Equipment/Supplies; *Guidelines for Investigating Chemical Process Incidents,* 1992; New York: Center for Chemical Process Safety; American Institute of Chemical Engineers, pp. 96-97.

[11] See reference 2.

[12] 29 CFR 1910.120(q)(5); See reference 2.

[13] 29 CFR 1910.120 - Appendix C (2); See reference 2.

[14] See reference 2.

[15] See reference 2.

[16] 29 CFR 1910.1030(b).

[17] OSHA (1992); *Occupational Exposure to Bloodborne Pathogens: Precautions for Emergency Responders;* U. S. Department of Labor, Occupational Safety and Health Administration; OSHA Publication No. 3130, p. 5.

[18] See for example, Union Oil Co. of California; Occupational Safety and Health Review Commission No. 85 - 0111; 13 BNA OSHC 1673, 2033, and 2165; (See 13 BNA OSHC 2037).

[19] Kulka Constr. Mgt. Corp.; 15 BNA OSHC 1870; 1992 CCH OSHD 29,829 (No. 88-1167, 1992); Astra Pharmaceutical Prods., Inc.; 9 BNA OSHC 2126, 1981 CCH OSHD 25578 (No. 78-6247, 1981).

[20] OSHA (1994); *Field Inspection Reference Manual;* U. S. Department of Labor, Occupational Safety and Health Administration; OSHA Instruction CPL 2.103, pp. III-19, and 20.

[21] NFPA (1993); *Standard for Professional Qualifications for Fire Investigator;* NFPA 1033, 1993; Quincy, MA; National Fire Protection Association.

[22] NFPA (1993); *Standard for Professional Competence of Responders to Hazardous Materials Incidents;* NFPA 472, 1993; Quincy, MA; National Fire Protection Association.

Health and Safety Considerations in Fire Investigation

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Investigation at the scenes of fires, explosions, and similar incidents is inherently dirty and hazardous. Each investigator should aim to reduce the risks to a minimum consistent with the scope of the planned examination. There will inevitably be occasions when the risk cannot be restricted to an acceptable level and the scene activities will have to be curtailed. Serious injury or death are too high a price to pay for the information which might be obtained.

The hazards to be considered in this presentation arise mainly after the fire is extinguished. The assessment and management of risks during firefighting are largely outside the author's expertise. Such information can best be obtained from people involved in training firefighters.

BACKGROUND

In the United Kingdom (UK), the Health and Safety at Work Act of 1974 is the primary legislation aimed at protecting employees in the workplace. This law places certain duties upon employers, notably to provide a safe working environment including suitable training, equipment, and so on. It also requires employees to take reasonable care for their own safety and that of others who may be affected by their work. All the requirements are, of course, qualified by phrases such as "so far as is reasonably practicable." A recent development has been the "safe person" concept, used when the workplace is outside the direct control of the employer (for example, a fire or crime scene). In this case the emphasis is on the employer selecting the correct worker for the task and providing sufficient information, training, equipment, and support to enable the work to progress safely.

Under this act various other regulations have been brought into effect. Initially, these originated and applied only in the UK, but membership of the European Union means that European directives are now applied in the UK as in other member states. Application and enforcement of all this legislation is carried out in the UK mainly by the Health and Safety Executive (HSE) on behalf of the Health and Safety Commission, a government department. These bodies together are broadly equivalent to OSHA in the United States. Unlike the United States, however, the UK has no direct equivalent of the NFPA. The UK Fire Protection Association (FPA) is a much smaller body which is only recently beginning to broaden its remit into publishing recommended practices and codes of conduct. There is also pressure for European standards to be developed in certain areas, although fire investigation and scene safety have not yet been proposed. At present, therefore, no equivalents exist of NFPA 921 or 907M which incorporate some safety advice, although some textbooks contain a small amount. The result is that throughout Europe, and especially in the UK, practitioners have tended to develop their own approach with little or no coordination or development of best practice. It became clear that the small team of specialist fire investigators within the Metropolitan Police Laboratory needed a guidance document and one was prepared. This generated considerable interest and the FPA approached the author for permission to publish it as a booklet aimed at a much wider audience.

SAFETY MANAGEMENT

In the UK, the terms "hazard" and "risk" have different meanings in health and safety circles. A hazard can be defined as something with the inherent

potential to cause harm or injury. Risk can be defined as the likelihood of harm or injury arising from the hazard. For example, when climbing a ladder, the hazard relates to the height and the risk to the likelihood of falling. In order to quantify and thus minimize a risk, it is first necessary to establish the nature of the hazard and then to establish what control measures are already in place and how they can be improved. This procedure is known as a risk assessment. Obviously, in a normal work environment, this process can be carried out mainly by or on behalf of management. However, where work goes on in places outside the employer's control and the safe person concept is in use, a general or model assessment may be made for all similar activities and then fine tuned on site by the trained individual involved. For staff of the Metropolitan Police Laboratory, this general assessment comprises both the Laboratory Safety Code and the booklet referred to above. Using such general advice together with information specific to the incident and physical evidence at the scene, the safe person is then able to conduct a full risk assessment.

To perform an adequate risk assessment, the fire investigator must:

- Correctly and accurately identify the hazard;
- Allow for existing control measures;
- Disregard trivial and inconsequential risks;
- Determine the likelihood of injury or harm arising;
- Estimate the severity of the consequences; and
- Obtain sufficient information to enable a decision on further control measures.

At the fire scene the investigator then uses his/her professional judgment as to whether taking a specific risk is justified under the prevailing conditions.

A hierarchy of control measures can be considered and/or applied to reduce the risk from a specific hazard:

- Prevent exposure to the hazard by discontinuing activity. (Is this examination likely to provide anything worth the risk?)
- Substitute a less hazardous activity. (If your normal methods lead to danger, can the same information be obtained by other means?)
- Isolate hazardous areas. (Is it really necessary to stand just there?)
- Restrict the number of people exposed. (Do you really need an audience?)
- Reduce the time you are exposed to the hazard. (Why take half an hour over a 5-minute job?)
- Use personal protective equipment. (Although usually the first line of defense, it is really a last resort—that hard hat will not protect you from everything!)

It is a requirement of UK law that any risk assessment carried out must be formally recorded in some way. Where relatively small or low-risk scene examinations are involved, it is often adequate to incorporate the assessment into the normal note-taking activities. However, larger or more complex scenes may require a more detailed treatment and the Fire Investigation Unit (FIU) has devised a printed form for this purpose. A protocol has been developed for fire investigators to ensure that the procedures developed for scene safety management are understood and followed.

SOURCES OF INFORMATION

In carrying out a risk assessment, it is necessary to consider both the information available from various sources about the hazards and to perform a physical examination. The quantity and quality of information available is very variable, but some of the most important sources are listed below:

- Firefighting personnel;
- Scene of crime examiner;
- Structural engineer;
- Utilities representatives;
- Responsible person for site or process;
- Company records (*e.g.*, chemical, biological, radioactive materials).

Of course in many cases, the initial fire investigator will be a person within the first two categories above. However, the normal working practice of forensic scientists from the FIU requires that the scene is first assessed by a trained crime scene examiner, who will in turn only be involved if the fire service (or another party) has alleged arson to the police. The main exception to this is when a fatality is involved, in which case police are always involved and the FIU will attend at once. Upon receiving a request to attend a scene, the scientist will, therefore, normally have access to a certain amount of safety information as part of the overall description of circumstances and this can be recorded at this stage. Further information which becomes available at the scene can be recorded at that time. Under UK law, any person who has knowledge of a significant hazard has a duty of care and must disclose that information to any other party likely to be affected. Each of the sources must, therefore, take steps to ensure that the necessary data are passed on and recorded. This, of course, applies equally to the scientists of the FIU. Again, normal working practices allow this to be achieved fairly readily. At the conclusion of the scene examination, a preliminary report is prepared and given to the client (normally the investigating police officer). This report gives a brief outline of the initial findings and includes a reference to any significant hazards encountered. This information can then be passed on to persons subsequently concerned with the scene.

PHYSICAL EXAMINATION (SELF ASSESSMENT)

A fire scene examiner can and must evaluate the hazards for himself/herself before performing the risk assessment. Again under UK law, the final assessment is the responsibility of the individual investigator and he/she also takes responsibility for anyone present at his/her request or working under direction. It is, therefore, imperative that the risk assessment is soundly based. Having taking note of all the available advice and information, some of which may well be contradictory, the investigator must be able to perform a physical appraisal of the problem areas and decide on the appropriate control measures. There is no doubt that this becomes easier with experience, sometimes of the bitter variety.

It is probably simplest to break down the physical appraisal by hazard types and give some general advice and examples for each. This is by no means a comprehensive list, since each fire scene presents its own special problems, but the general principles can usually be applied.

Structural Safety

Most fire investigations take place within buildings or other structures. The fire often damages these in such a way as to produce weaknesses, failures, or exposure of hazardous materials. The examination of building structures is, therefore, the first consideration. The approach to the scene can reveal a great deal about the potential risks present, even if the location of the fire itself is not visible at this stage (*e.g.*, a room within a house). Broken glass, hanging roof materials, broken masonry, etc. may be apparent; firefighting or utilities activities may still be in progress; there may be mobile hazards or aggressive animals (or even people) in the vicinity. At this stage, it is often possible to locate storage compounds, warning signs, etc.; these will be considered later. At larger scenes, a walk around the whole of the affected area at a sensible distance is advisable. This will reveal a great deal about the size, construction, and peculiarities of the scene; if possible, a high vantage point should be found as this can help to visualize much of the internal damage. In both the initial external assessment and subsequently, when the scene is entered and a more detailed appraisal is carried out, a convenient method is to consider the structure from the top down. A number of questions can then be posed for each feature concerning the hazard itself and potential control measures.

- **Roof**
  How is the roof constructed and covered?
  How extensive and severe is the damage?
  Are there loose or unsupported areas?
  Is it sufficiently weakened to fail under design loads?
  Can the area beneath be avoided completely?
  If necessary, can it be made safe (*e.g.*, by props, removing loose sections, etc.)?

- **Walls**
  How are the walls constructed and supported?
  Is there evidence of deformation or disruption?
  What would be the effect of failure on the rest of the structure?
  Are door and window lintels firmly fixed?
  Is demolition and/or shoring up necessary?

- **Floors**
  What materials are involved in the floors and any associated ceilings?
  How are the floors constructed and supported?
  What is the extent of the damage?

Is it possible to inspect the floor from beneath or to expose areas for examination without standing on it?
Can holes or weak areas be avoided or bridged (*e.g.*, by using crawling boards)?

♦ **Stairs**
How are the stairs constructed and fixed to the walls?
Is there evidence of disruption (*e.g.*, sagging, pulling away from wall)?
What is the extent of visible damage?
Is it possible to examine the underside?
Is it necessary to use the stairs at all?

♦ **Others**
Are there any unstable, free-standing parts of the structure?
Can these be avoided or made safe?
Are there large glazed areas involved and is the glass firmly fixed?
Are lifts (elevators) at the bottom of their travel?
If not, are they firmly suspended by undamaged fixings?
Are there any temperature indicators which show that structural steel could have reached over 500°C (950°F) and therefore be greatly weakened?
Is there any evidence of insect or fungal damage to structural timbers (woodworm, termites, dry rot, etc.)?

Environmental Factors

Certain aspects of the general scene environment may present hazards to a greater or lesser extent. Obviously, if the structure is positioned in an area which restricts access or makes it difficult to position safety equipment correctly, this must be taken into account in the overall assessment. Examples include steep hillsides, marshland, and places prone to subsidence. Probably the most common environmental hazard is the weather. Even moderately strong winds can cause substantial movement in a fire-damaged structure, while heavy rain can lead to both flooding of exposed or low-lying parts of the building and greatly increased loadings on roof elements. Such loadings can also be produced by heavy snowfalls; these are not unknown even in the UK, but are much more of a problem in many other countries. Even fine, dry weather may bring with it the risk of sunburn and heatstroke and make dust much more of a problem. Other environmental factors which may need to be considered in the risk assessment include local flora and fauna, proximity to highways or rail tracks, and services or supply lines to nearby, unburned structures.

Services

In developed countries, most dwellings, commercial buildings, and many other structures are supplied with electricity. This may be locally generated, but is more commonly drawn from a distribution network. In addition, except in more remote rural areas, gas and fresh water are often supplied from similar networks and drainage is provided. In the UK, such distributed services are known as "mains supplies." The electricity supply to domestic premises is 230V AC, single phase, at 50 Hz. Many commercial premises have 3 phase supplies, in which case the phase to phase voltage is over 400V. The UK gas supply uses natural gas which is more than 95% methane. Some areas of the UK and some individual premises are not supplied with mains gas and use liquefied petroleum gas instead, either as portable cylinders or in fixed installations.

♦ **Electricity**

Clearly the main risk from electrical power systems, especially when damaged, is electric shock. In general, this is rarely a problem if the voltage is below about 150V AC as the resistance of the human body limits the current to subdanger levels. However, low voltage systems which can deliver high currents through conductive pathways (such as automotive applications) can lead to high localized temperatures with the consequent risk of burns.

The normal control measure is to ensure that the supply has been disconnected. In most building fires, the consumer unit will have been switched off by the first firefighting attendance, but should always be checked. If it is not possible to do so, due to extent of damage, extensive tampering, or inability to locate the equipment, it is usually necessary to involve the company who may terminate the supply outside the premises. Particular care should be taken if a so-called uninterruptable power supply (often installed where data processing systems are in use) may be present, or if there is evidence of tampering with the supply. Low voltage DC supplies, such as those used in vehicles, can usually be dealt with simply by disconnecting the battery. However, if the power is believed to have been interrupted, it is essential to test

exposed conductors with a suitable voltage indicator before handling them.

- **Flammable Gases**

  These include mains gas (methane in the UK), liquefied petroleum gas, and some industrial supplies. The main risk is clearly one of ignition and subsequent fire or explosion, although questions of toxicity may also arise. Again, the best long-term control measure is to remove the source of the supply if possible, by isolating valves or physical removal of cylinders. In the short term, it is vital to exclude ignition sources. Nonflammable gases can also present potential explosion problems if the cylinders have been exposed to heat; these must be cooled and removed to a safe distance as soon as possible.

- **Water and Drainage**

  Where a water supply has been damaged or interrupted, the risks associated with a flooded scene become more immediate. These include slippery surfaces (and ice in cold weather), obscured changes in floor level, unknown depth of cellars, etc. It is often necessary to terminate the water supply outside the premises. If the drainage system has been broken into or backflushed (*e.g.*, with firefighting water), additional biological hazards may be present. Adequate protective clothing can mitigate against these.

Processes and Materials

Many commercial undertakings, research facilities, etc. involve materials as feedstocks, intermediaries, or products which are inherently hazardous. In the UK, a set of regulations known as Control of Substances Hazardous to Health require users to keep details of all such materials and their normal control measures. This information must be made available to anyone with a legitimate interest such as a fire investigator. Access to these details will enable the control measures to be determined and the risk correctly assessed. Signs and labels should be carefully noted, including any HazChem or UN codes, together with color coding of any pipes, ducts, bottled gases, etc.

The processes themselves may also involve significant hazards, such as very high or low temperatures and pressures which must be taken into account. Speaking to a reasonable person familiar with the materials and operations involved is essential. This could include representatives from the organization involved, local factory inspectors, and specialists from the industry or trade association.

Special problems arise if illicit manufacture is involved (*e.g.*, drugs of abuse). It is unlikely that rigorous procedures are in force, that regulations have been adhered to, or that much information will be available. In such cases, the investigator will have to exercise extreme caution and attempt to consult with a more knowledgeable person, such as a forensic drug analyst.

Vehicles

There are extra hazards involved in the investigation of vehicle fires which do not normally arise in other types of scenes. The most commonly encountered vehicle fires involve road transport; some of the same problems arise in railway trains, ships, and aircraft, but these also have individual features which cannot be covered here. Specialist advice should be sought as necessary.

The main risks likely to be encountered when examining fire-damaged road vehicles fall into the following groups:

- **Fuels and Lubricants**

  Contact with these can cause dermatitis or even cancers. Inhalation of fuel vapors can be extremely dangerous, especially in confined spaces.

- **Toxic and Corrosive Chemicals**

  Hydrogen fluoride from heat decomposition of some fluoroelastomer compounds is probably the worst of these at present, but it is possible to encounter others such as azides from air bag propellant systems. In the future, electrically powered vehicles are likely to be more widespread and many of the electrical storage systems envisaged involve such chemicals as sodium and lithium metals and various metal hydrides.

- **Structural Components**

  These include gas-filled dampers which can fail explosively during or after a fire and other sealed hollow sections which may be sufficiently weakened by heat for the increase in internal pressure to cause fragmentation.

- ♦ **Impact Protection Systems**

  If these have not already been activated, they can present considerable hazards to the investigator. Air bags can be triggered unintentionally, or release the chemical charge as described above. Some vehicles have pretensioned cable systems designed to prevent the engine intruding into the passenger compartment. Cutting these cables will cause them to part violently. Auto-erect roll protection could also be triggered by injudicious jacking or raising of the vehicle. Modern unitary construction vehicles depend on a few key elements for much of their structural strength and if these are cut (for example, in rescue attempts) the integrity of the vehicle will be seriously impaired.

- ♦ **Electrical Systems**

  Although normally very low voltage, they are capable of delivering extremely high currents. As previously mentioned, this can lead to extreme local heating and subsequent danger of burns.

Chemical and Biological Hazards

It is impossible to provide a comprehensive list of all the potential chemical and biological hazards that an investigator could encounter. Even common household and garden products can present problems if the exposure route is different from normal, the dose is greatly increased, or the material is affected by heat. Broadly speaking, the two main areas of risk involve inhalation of gases, vapors, aerosols, or particulates and direct contact with any of these or, more commonly, liquids. Respiratory protection should, therefore, be considered together with an appropriate level of protective clothing. Eating, drinking, and smoking in the scene (or while wearing protective clothing which has been contaminated) should be avoided. There are numerous specialist texts dealing with the dangers of, for example, asbestos or beryllium, and these should be consulted.

SAFE WORKING PRACTICES

Having assessed the hazards intrinsic to the scene, decided on the appropriate control measures, and carried out the risk assessment up to this point, work may then begin. It is important to realize, however, that the tasks undertaken as part of the investigative process may introduce further hazards. These may arise either as a function of the work itself, or because the scene becomes modified by the investigation process. It is essential to keep these factors in mind and to perform, in effect, a rolling risk assessment as the work proceeds. There are simple practical precautions which may be used at most scenes to safeguard the investigator.

Personal Protective Equipment (PPE)

Although last in the hierarchy of control measures, this will in fact usually be the first one adopted. It is essential to recognize that, while important, PPE has limitations. The term is generally taken to include clothing, footwear, gloves, headgear, etc. together with respirators, sight and hearing protection, and similar accessories. The minimum acceptable provision for virtually all fire scenes comprises stout overalls, helmet, reinforced boots, gloves, and goggles or visor. Special requirements of the scene may require these to be augmented by waterproofs, disposal overalls, or respirator masks. The most important aspect is that the PPE chosen must be suitable for the job in hand, but is not a substitute for good risk assessment and careful working.

Communications

It is important to establish good lines of communication. The most obvious method is to simply be within voice contact of a colleague or other responsible person (such as a fire or police officer) while the investigation is in progress. At larger scenes, it may be necessary to use two-way radios or even mobile phones. The responsible person should remain in a safe place, preferably outside the scene itself. Solo scene examination is bad practice for a number of reasons including safety provision, but if it is unavoidable the investigator should arrange to call in to a prearranged point (*e.g.*, the office) at regular intervals. Should the call fail to be made, help can be dispatched.

Demolition and Making Safe

During the structural appraisal, a decision may have been reached (usually by or with a structural engineer) to demolish part or all of the structure or to support areas in danger of collapse. It is essential for the investigator to liaise closely with both the engineer and the contractor involved. There are advantages and disadvantages involved in both courses of action and the investigation may be prejudiced if these are not clearly understood. During the actual demolition or making safe, it is advisable to withdraw from the scene as additional hazards will be present.

Access and Visibility

It is essential to ensure a safe and reasonably clear access route to the area of interest, if necessary, marking and protecting this to ensure it remains so. In larger or more severely damaged scenes, it is wise to locate a second escape route. In the area where most of the physical work will take place (*e.g.*, clearance and reconstruction), there should be sufficient room for maneuver for the minimum number of people absolutely necessary. Inspection for overhead and underfoot hazards should be a continuous process. For example, hanging roof coverings or other objects should be noted and, if possible, made safe; floors and stairs should be inspected from below, if possible, in case severe damage has been obscured by fallen debris.

Fire scenes are best examined, where possible, in natural daylight. This may require the removal of security boarding in some cases—of course, this also has associated risks. Where natural light is unavailable or insufficient, floodlighting will be required. This introduces additional electrical and high temperature hazards, but is generally worth the effort. Handlamps are useful for small scale inspections or detailed scrutiny of localized damage, but are totally inadequate for a full examination.

Visibility can also be reduced by obscuring features such as smoke, steam, dust, etc. which should be cleared by ventilation. Flooding can obscure changes in floor level and the depth of standing water should always be checked.

Access Aids

Sometimes the area of interest is not readily accessible without the use of other equipment. This includes ladders, crawling boards, scaffolding, props, and jacks. Although the larger items are normally erected or installed by specialist contractors, individual investigators often need to use ladders and boards. It is important to know and adopt the correct methods for safe use of such items, such as footing and securing of ladders and supporting boards at intervals. There is a great deal of information available on such matters (in the UK, the HSE, and various trade bodies publish guidance notes) and the investigator should be familiar with it. It is also important to choose the right equipment for the task; ladders are for climbing, not crawling, and so on.

Tools and Equipment

The same broad guideline applies to tools; choosing the right piece of equipment for the job and using it correctly are key factors in working safely at scenes.

Most of the time, the investigator will be using hand tools. The main hazards from these are postural (*e.g.*, pulled muscles and back strains) caused by using the tool wrongly or in too confined a space, and impact (*e.g.*, stabbing, crushing, and cutting). These can again be avoided by using the right tool correctly and ensuring that cutting or striking edges are pointed away from the operator.

Occasionally, power tools will be required. The current trend is for smaller and more powerful battery-powered appliances, but it may be necessary to use higher-voltage supplies or hydraulic equipment. Many of the risks are as above, but with the added problems of the higher power and speed involved. There may also be an increased ignition risk from electrical or friction sparks.

Clearance and Reconstruction

To investigate fires, it is often necessary to remove extraneous debris and replace items of interest in their original positions. Good planning can facilitate the efficient and safe conduct of these operations. It is important to locate a suitable area for deposition of unwanted items, to consider questions of access and underfoot conditions, and assess the physical characteristics of the scene. For example, the size and weight of individual items, the angle of attack, dimension of access openings, and stability of associated materials all need to be considered. When excavating, care is needed near props or unstable areas and around services (*e.g.*, incoming electrical mains). For large scale excavation, powered machinery may be needed; operation is best left to a skilled person working under the investigator's direction.

If damaged furnishings or fittings are reconstructed, it may be necessary to support or brace them so that they remain stable during subsequent activities. The methods used for doing this are usually improvised and will, of necessity, vary widely from case to case.

First Aid

It is strongly advised that all fire scene examiners should be familiar with basic lifesaving and resuscitation techniques and have access to a good first aid kit. Although it could be argued that these skills are redundant if the investigator is the casualty, it is common (and indeed good practice) for more than one scene examiner to be present at all times. Even if the only help available is from an untrained person, the investigator will be able to advise as long as he or she is conscious.

Considerations for Arson Investigations in NFPA 921 - Guide for Fire and Explosion Investigations

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Although the precise legal definition may vary among jurisdictions, arson is the crime of maliciously, and intentionally or recklessly starting a fire. The evidence that an arson has been committed generally arises from a finding by the fire investigator(s) that the cause of a given fire was incendiary; that is, that the fire was deliberately set under circumstances in which the person knew that the fire should not be set. Some of the most compelling physical evidence is the identification of a known substance or substances at the point of origin and the determination that the substance was present because it was used to start or accelerate the growth or spread of the fire. Such a substance is often called an accelerant [National Fire Protection Association (NFPA) 1995]. The determination of the presence of a substance and its identification is the role of the forensic laboratory. The determination of its role in the cause of the fire and whether or not it was an accelerant, is the role of the investigator.

In addition to the determination of the use of an accelerant, other physical evidence at the fire scene is frequently reviewed in the search for clues of an incendiary fire. Some of this evidence has value and some does not, at least not without laboratory verification.

Many of the issues relating field evidence to the finding of an incendiary cause are addressed in *NFPA 921: Guide for Fire and Explosion Investigation* (NFPA 1995). It is important for those individuals involved in examination of possible arson evidence and fire scenes to be aware of these issues and how they relate to the finding of an incendiary fire cause.

BACKGROUND

The origin of a fire is the area or the point where the ignition source came in contact with the first fuel involved. The cause is the circumstances that brought the ignition source and the fuel together.

Historically, fire investigators have considered the determination of origin and cause to be a mixture of art and science. The basis for the science was certain properties of materials (such as melting or ignition temperatures and flash points of liquids) taken from handbooks that were not generated for fire investigation purposes (*Chemical Engineers' Handbook* 1973; *Mark's Standard Handbook for Mechanical Engineers* 1978; Weast 1990). The art consisted of interpreting a variety of burn damage patterns, along with inferences drawn from experience and material properties to locate the origin of the fire and its cause. Since investigators relied heavily upon experience, a number of burn patterns and types of damage had come to be considered to be indicators of fire growth rate, intensity, or the presence of liquid accelerates. The evolution of many of these indicators came about through the application of *post hoc ergo propter hoc* logic. Simply stated, that means that if a given fact (A) is associated casually once with another fact (B), then the presence of fact (B) presumes fact (A). Another way of stating this would be to say "I am tall; the President is tall; therefore, I am the President."

In fire investigation, this would be to say that if a hole were found in the floor after a fire where gasoline was known to have started or accelerated the fire, the presence of a hole in the next fire investigated

indicated the use of gasoline in the second fire. This conclusion is wrong, since many processes in the growth, spread, and extinguishment processes of a fire can produce a hole.

Many erroneous fire origins and cause indicators have been passed on through the apprenticeship method of fire investigator training and have appeared in many fire investigation textbooks and formal training programs. They persist today largely due to a lack of understanding by many people in the fire investigation community of the basic processes of building fires. This situation is, however, changing rapidly. This paper will summarize the development of modern fire investigation technology and present some examples of the changes in the "folklore."

UNDERSTANDING FIRE GROWTH AND SPREAD

Beginning in the early 1970s, researchers in universities and government laboratories in the United States and elsewhere undertook studies to try and understand the mechanisms that control the ignition, spread, and growth of fires in buildings. This work involved many experiments where fires were set in small- and large-scale facilities and allowed to grow unimpeded. The researchers used both actual furnishings and specially-prepared fuel packages. They collected data on gas temperatures, smoke production, and the rate of energy release and subsequently related the data to the fuels involved and to the test compartments and their openings.

The resulting work showed that, while different fires follow different courses with respect to growth, there is a characteristic process associated with compartment fires. Details of this process can be found in a number of references (Drysdale 1985; NFPA 1988) and are briefly described below.

Once fire is initiated in a compartment, the smoke rises to the ceiling above the fire and spreads outward, forming a layer. This layer contains the hot gases, smoke particles, and unburned combustion products of the fire. If the fire continues to grow and increases its energy output, the layer at the ceiling will thicken and descend towards the floor; the temperature in the layer will increase dramatically. As the layer descends, the energy radiating from the layer will begin to heat other objects, such as furniture in the compartment, that are not yet burning. If the door is open, some of the smoke and hot gases produced will leave the compartment and spread to other spaces.

Once the temperature in the layer reaches about 1100°F, there will be enough energy radiating on the other fuels to begin to cause ignition of those items close to the layer. This is the beginning of the process called flashover and represents the transition from a fire that is controlled by the first fuel ignited to one that is controlled by the total fuel in the compartment and by the size of the openings in the room. The size of the openings will control the amount of air that enters the compartment and, thus the amount of combustion that can occur.

Once the fire reaches the condition where the air flow is limited, the fire is said to be in full-room involvement or postflashover. The hot gas layer will be at or very near the floor. The combustion products leaving the room will most likely ignite, and the process of fire growth and spread will propagate to the next compartment. At or about this time, windows in the compartment of origin may crack or break out.

The process of fire growth to postflashover conditions produces very large amounts of energy and causes extensive charring and damage throughout the space. Postflashover burning can result in, for example, holes in a floor. It should be noted that the time to reach flashover or full-room involvement is frequently on the order of only a few minutes for fires involving modern furnishings made of petrochemical-based foam plastic materials. This is important since a fast-growing fire is often interpreted by investigators as an indicator of arson.

After extinguishment of a fire, the investigator can be faced with a variety of patterns that reflect the entire burning history of the compartment or building. In this situation, the interpretation of burn and damage patterns is difficult with respect to identifying those that were developed at the early stages of the fire. It should be noted that not all fires reach flashover or full-room involvement, due to conditions such as limited fuels or early extinguishment. The earlier a fire is extinguished, the more can be learned from the damage patterns.

DEVELOPMENT OF FIRE INVESTIGATION GUIDELINES

Recognizing the need to bring together the fire investigation and fire science communities to evaluate the scientific basis for investigative practices, the NFPA formed a committee on fire investigation in 1984. The committee's scope was to have primary responsibility for documents relating to techniques to be used in investigating fires, equipment, and facilities

designed to assist or be used in developing or verifying data needed by fire investigators in the determination of origin and development of hostile fires (NFPA 1986).

In 1985 the committee held its first meeting and began development of an outline and drafted some initial text. Over the next 5 years, the committee met 3 to 4 times a year and prepared a draft document with 13 chapters. In 1991 that document was circulated to the fire protection and investigation community, and comments were solicited. The committee received and acted upon in excess of 280 public comments. The first edition of NFPA 921 was issued in February 1992.

NFPA 921 is a guide, not a standard. The basic difference is in the language used. Where a standard uses words such as "must, shall, and will", a guide would use the words "may, should, and can." Having said this, NFPA 921 is recognized as a *de facto* standard of care in training of investigators in many jurisdictions such as Arizona, Connecticut, and Virginia. It is also listed as reference material for the International Association of Arson Investigators and endorsed by the National Association of Fire Investigators. The document is also being actively used in support of direct testimony and as the basis of cross-examination in both criminal and civil courts.

The scope statement for the document stated that NFPA 921 "is designed to assist individuals who are charged with the responsibility of investigating and analyzing fire and explosion incidents and rendering opinions as to the origin, cause, responsibility, or prevention of such incidents" (NFPA 1992).

The first edition contained a chapter defining basic terminology and methodology, an introduction to fire science, and a discussion of the origin and interpretation of fire patterns. Other subjects included legal considerations, planning an investigation, sources of information, and recording the scene. Physical evidence, safety, origin and cause determination, and explosions were also covered.

The second edition (NFPA 1995) is now available. This edition includes new sections on motor vehicle fires, management of major fire investigations, incendiary fires, and appliance fires. The new edition also incorporates materials on electricity and fire from another NFPA document that is now withdrawn (NFPA 1988).

EXAMPLES OF ARSON-RELATED ISSUES ADDRESSED IN NFPA 921

As previously discussed, many fire investigators have based their decisions regarding origin and cause on fire scene indicators that are either wrong or subject to alternative interpretations. In the limited space available, it is not possible to include all those covered in NFPA 921. A number of the more common misconceptions will be presented and discussed below. In addition to a full reading of NFPA 921, the reader is urged to review Lentini *et al.* (1992), a detailed study of structures that burned in the Oakland, CA, fire in 1992.

INDICATIONS OF FIRE ORIGIN

In order to determine the cause of a fire it is necessary, in most cases, to know where it started—the origin. Absent the origin, the first fuels ignited, the ignition source, and the casual circumstances may not be identified. Location of the correct origin is important since the presence of identified ignitable liquids in samples taken may result in an incorrect incendiary cause determination.

Origin determination is often accomplished by evaluation of the degree of damage based on the assumption that the greatest damage will be where the fire burned the longest. Such assumptions should be used with care since a spreading fire may encounter highly flammable materials in an area far from the origin or burn-through of ceilings or floors may result from building collapse or firefighting activities (NFPA 1995).

INCENDIARY CAUSE INDICATORS

The type of damage, such as melting, charring, and changes in mechanical properties has often been used to support a finding of the presence of ignitable liquid accelerants.

- **Burning Temperatures of Liquid Accelerants**

  Investigators have frequently held the opinion that liquid accelerates produce higher temperatures than ordinary combustibles. Using the melting temperatures of known materials, conclusions have been drawn that accelerants were present. For example, one text states that knowing that aluminum has

melted (1200°F), but brass (1710°F - 1810°F) has not, is useful in determining if an accelerant was present in the fire (Carroll 1983). NFPA 921 provides data on reported flame temperatures, including wood at 1800°F and gasoline at 1798°F. From the example above, one could not actually tell whether an accelerant was present. In fact, benzene, gasoline, and JP-4 (all of which could be potential liquid accelerants) have temperatures well below that of wood; kerosene is only 14°F higher. It is also pointed out that melting of metals may be the result of alloying taking place during the fire at temperatures lower than the melting points of the individual metals (Beland *et al.* 1983; NFPA 1995).

♦ Surface Appearance of Wood Char Blisters

There are two characteristics of the char blisters that have been used to draw conclusions regarding the speed at which a fire grew: blister geometry and surface appearance. Geometry relates to the size and shape of the blisters, frequently referred to as "alligatoring", since the surface resembles the hide of an alligator. The usual interpretation is that a slow heat buildup produces a small flat square or rectangular blisters with shallow grooves. Rapid burning with intense heat produces larger, more rounded blisters with deep grooves, and that a mixture of the two types of blisters indicates that an accelerant was thrown on the wood (Phillips and McFadden 1982). Laboratory testing (Ettling 1990; French 1979) and full-scale experience (DeHaan 1990) has not confirmed these theories. NFPA 921 advises investigators not to claim indications of an accelerant on the basis of wood char alone (NFPA 1995).

♦ Depth of Char

Fire investigators widely accept that wood chars at a rate of 1 inch in 45 minutes and have used this rate to estimate the time of exposure of wood to flaming combustion (Roblee and McKechnie 1988). Many investigators have measured the depth of char and used this measurement to determine the time a normal fire most likely started. Thus, if witness's statements or other evidence supports a shorter burning time, the presence of an accelerant is often inferred. However, rate of charring is a function of many factors, including the species of wood, the geometry of the material exposed, and—most importantly—ventilation (NFPA 1995). Charring rates may vary from 0.4 inches to 10 inches per hour (Drysdale 1985).

♦ Collapsed Springs

Frequently investigators note that the springs of mattresses or upholstered furniture involved in a fire have collapsed. Work by forensic scientists at the FBI (Tobin and Monson 1989) and referenced in NFPA 921 points out that some fire investigation texts have stated that collapsed springs are an indicator of a cigarette ignition and that flammable liquids cannot cause the collapse. Others have stated that liquid accelerates cause spring collapse and the collapse can be evidence of an incendiary cause. The FBI's work concluded that either can cause collapse and that factors such as exposure time, load on the spring, and cooling history all have effects; the FBI's work further concluded that collapsed springs are not a reliable indicator of either smoldering or flaming exposure.

♦ Flammable Liquid Burn Patterns

Fire investigators often use the term flammable liquid burn pattern to describe patterns they use to support a finding that a fire was incendiary and that liquids were used as an accelerant. Very frequently these patterns serve as the sites from which debris samples are taken for laboratory analysis. One text (Roblee and McKechnie 1988) states that flammable liquid burn patterns on flat surfaces form an ink blob-like outline and that patterns will be similar on floors and carpeting. Full-scale testing and examination of floors and floor covering materials in accidental fires or in fires set for replication purposes (Lentini 1992) have shown that irregularly-shaped patterns that have the appearance of spilled liquids can be formed by many other processes, such as postflashover burning at the floor level, burning of melted foam plastic materials, or by the presence of clutter that protects the floor and allows irregularly-shaped exposed areas to be selectively burned. NFPA 921 (NFPA 1995) suggests that suspect patterns be verified by laboratory analysis. It is also

noted that pyrolysis products can be found in fire debris samples in the absence of the use of accelerants (Howard and McKague 1984). It is suggested in NFPA 921 that in assessing fire debris from carpets, a portion of the comparison sample be burned and the gas chromatography results compared with those of the debris sample. The recommended procedure for gas chromatography analysis is ASTM E1387 [American Society for Testing and Materials (ASTM) 1990].

- **Spalling of Concrete**

Spalling or removal of surface chips from concrete has been offered as evidence of the presence of an ignitable liquid accelerant. The literature indicates that there are many reasons for this to occur under fire conditions and an ignitable liquid is only one (Copier 1983; Malhotra 1984; Smith 1991; Suter 1983). NFPA 921 notes that moisture expansion in green (new) concrete and differential expansion between surface finish, matrix and aggregate or matrix and reinforcing steel are that principle mechanisms and that spalling results from high temperature and rapid rates of heating or cooling not necessarily from an accelerant (NFPA 1995).

EVIDENCE COLLECTION

Suggested techniques for collection of samples for laboratory identification of potential accelerants are included in NFPA 921 (NFPA 1995). Emphasis is placed on avoiding contamination of containers and cross-contamination of samples, documentation and collection techniques, and selection of containers. Note is also made of methods for collecting electrical components, appliances, and other materials for laboratory analysis. NFPA 921 references specific ASTM publications as providing guidance collecting, labeling, documenting, examining, and testing of items (NFPA 1995).

SUMMARY

Much has been learned about ignition, growth, and spread of fire that can supplement and improve techniques used by fire investigators with regard to the identification and collection of physical evidence of an incendiary fire cause. While laboratory analysis plays an important role, much of the evidence used today is found at the scene. In the past, the field evidence discussed above was thought to be conclusive evidence of an incendiary fire cause. Today, inferences to be drawn from fire damage and patterns are less clear and research and new techniques and applications of technology need to be developed. Forensic scientists and laboratory personnel are urged to review NFPA 921 and become more involved in the scene investigation process. The involvement range from suggesting better collection techniques to visiting actual fire scenes or applying techniques such as infrared or electron microscope analysis to fire debris.

NFPA 921 covers a wide range of recommended practices. Like all NFPA documents, it is reviewed and updated on at least a 3-year cycle with not more than 5 years between reviews. NFPA 921 is open for proposals from the public regarding suggested changes or additions and the proposals generated by the committee are open for public comment. Each copy of NFPA 921 contains a form to be used for submitting proposals. The forensic community can use these mechanisms to provide direct input to the document.

Continued and expanded use of NFPA 921, both in the field and in training and education, can lead to more accurate origin and cause determinations and to improved evidence for arson prosecution. Improved fire safety and lower fire losses through better codes, standards, and fire prevention practices can also result.

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NFPA 921 and Today's Fire Investigator

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Evidence—there are three types of evidence—demonstrative, documentary, and testimonial[1]. Demonstrative evidence is normally considered to be a thing[2]. Documentary evidence consists of reports, notes, and written statements[3]. The last category—testimonial evidence—is your opinion as expressed under oath[4]. Today, I would like to concentrate on the last two areas of evidence—documentary and testimonial.

First let us assume that we have a case that was extremely well documented and there is no disagreement as to the facts. Photographs, measurements, and videotapes all agree exactly on the conditions that existed after the fire. It would seem that this situation would lead to all of the experts reaching the exact same conclusion.

Let me give a hypothetical example. You are scheduled as a witness. You enter the courtroom and are allowed to hear the testimony of the other expert which goes as follows:

The length of time the fire burned can be easily determined because wood will burn at a rate of 3/4-inch per minute[5].

It can also be shown that a flammable accelerant was used as proven by the collapsed bed springs and the spalling of the concrete on the floor in front of the sofa.

You sit in the back of the courtroom. You are convinced that these statements are incorrect, but the testimonial evidence is backed up by nationally-accepted documentation. Where do you go from here? If you are not well prepared, you go home, call it a bad day, and learn from the experience.

If, on the other hand, you are well prepared, you have a copy of 921 with you, a copy of *Kirk's Fire Investigation* in your car, and copies of back issues of the *Fire and Arson Investigator* at your office. Being very familiar with these documents or having a good index to the documents will allow you to quickly show that although the previous witness spoke in good faith, the resources he used are out of date. More current research will show:

"... no specific time of burning can be determined based solely on depth of char."[6]

"The collapse of springs cannot be used to indicate exposure to a specific heat source, such as 'flaming accelerant'...."[7]

"The presence or absence of spalling at a fire scene should not, in and of itself, be construed as an indicator of the presence or absence of liquid fuel accelerant."[8]

Additional information about spalling can be found in *Kirk's Fire Investigation* on page 121 or in the *Fire and Arson Investigator*, volumes 42, 43, and 45.

The point of the above is not to emphasize that some of the publications cited as references are out of date, the point is that there is a need for all of us to stay up to date. What is accepted truth today may be hearsay tomorrow. NFPA 921 is fairly new and the information is reasonably accurate and reliable. Some years in the future, I am sure there will be some portion of 921 that is shown to be incorrect.

The use of NFPA 921 has grown considerably since its adoption only a few years ago. When you utilize any code or standard, I recommend that you carefully review the first chapters. The opening chapters contain generalized statements about the scope and purpose of the standard. If you were to review the purpose[9] of NFPA 921, you would find such words as systematic, technology, analysis, and

accurate. Chapter 2 explains the basic methodology to be used in conducting an investigation and emphasizes the Systematic Approach.[10] The recommended systematic approach to be used is the scientific method. Almost a full page of text is used to describe the scientific method and its application to fire investigation, so allow me the liberty to summarize the key issue. When you do an investigation, be certain of your conclusions. Ask yourself, do I know the facts, what conclusions can be derived from those facts, what testing exists to support those conclusions, and are there alternative explanations.

For too many years, fire investigators have based their conclusions on information they obtained from the investigator who had the job before them. A mistaken theory by one investigator was passed on as fact to the next investigator. Only a minimum amount of scientific test data was available and only a small part of that was actually known by the investigators in the field.

Today, the fire investigation community has made a start towards establishing a scientific background for the investigation of fire. Many of the old beliefs now have some specific test data to support them. Some of the old beliefs have been shown to be incorrect and need to be discarded, although they are still in use in some areas. The future is sure to bring change. Hopefully, this change will only result in slight course corrections spread across a long period of time, but change is inevitable.

If we as investigators wish to have ourselves judged as competent, we must remain current. You must continually stay up to date on what is happening in your chosen field or expertise. You do that by attending conferences such as this one. You do that by belonging to local chapters of the International Association of Arson Investigators and participating in their activities. You do that by subscribing to appropriate publications, reading them, and developing some type of system to be able to retrieve the information you learned, so you can site that source when the time arises.

The following is an index that I have prepared. This document is designed to permit you to check three separate documents to see what is being said in a particular area. It may not provide a specific answer to the question you are asking, but it should provide you with a background that identifies the major issues involved. I hope that you will use this document and I invite your comments on how it can be improved.

REFERENCES

[1] NFPA 921, Section 5-3.2

[2] NFPA 921, Section 5-3.2.1

[3] NFPA 921, Section 5-3.2.2

[4] NFPA 921, Section 5-3.3

[5] Kirk, Paul. *Fire Arson Detection*, Student Manual, #7, Pages 2-4. National Fire Academy and Fire Investigation, Page 80.

[6] NFPA 921, Section 4-5.5 - Misconceptions About Char.

[7] NFPA 921, Section 4-14 - Collapsed Furniture Springs.

[8] NFPA 921, Section 4-6.1 - Misconceptions About Spalling.

[9] NFPA 921, Section 1-2 - Purpose.

[10] NFPA 921, Section 2-2 - Systematic Approach.

ARSON PUBLICATION INDEX

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Arc	921	1-3			Arcs, Electrical	921	14-4.4		
Arc	IAAI	42	43	4	Arcs, Nonconductors	921	14-4.4.5		
Arc	Kirk	205			Arcs, Parting, Electrical	921	14-4.4.3		
Arc Beads	IAAI	17	44	4	Arc-Distance	IAAI	37	44	2
Arc Ignition & Static	921	14-8.6			Arc-High Resistance	IAAI	61	42	4
Arc Jump	921	14-4.4			Arc-Temperature	IAAI	20	44	4
Arc Not Ignite	921	14-4.4			Arc/Hirg Resistance	IAAI	62	42	2
Arc Path	IAAI	43	44	2	Area of Origin	921	1-3		
Arc Residues	IAAI	58	42	3	Area Patterns	921	4-19		
Arc Resistance	IAAI	42	41	4	Areas of Demarcation	921	4-3.1		
Arc Temperature	921	14-4.4			Armored Cable	IAAI	36	43	2
Arc Temperature	IAAI	48	41	4	Armored Cable-Oxidized	IAAI	36	43	2
Arc Temperature	IAAI	30	43	2	Aromatics	Kirk	257		
Arc Tracking	921	14-4.4.5			Arrow Pattern	921	4-3.4		
Arc Tracking	IAAI	35	42	2	Arrow Pattern	921	1-3		
Arc vs. Gases	IAAI	21	44	4	Arrow Patterns	921	4-17.6		
Arc vs. Ignition	IAAI	21	44	4	Arrow Trading	IAAI	43	41	1
Arced Circuits	IAAI	36	44	2	Arson	921	5-4.1		
Arced Conductors	921	14-5.2			Arson	921	1-3		
Arced Holes	IAAI	43	43	4	Arson	IAAI	43	43	2
Archeology	IAAI	49	44	4	Arson	Kirk	323		
Archer	IAAI	40	41	1	Arson	Kirk	105		
Architectural Drawings	921	8-4.6			Arson Dogs	IAAI	50	43	3
Architectural Schedules	921	8-5			Arson Dogs	IAAI	22	45	1
Arcing	IAAI	43	44	2	Arson for Profit	IAAI	14	42	4
Arcing	IAAI	30	43	2	Arson for Profit	IAAI	50	40	3
Arcing	Kirk	212			Arson Immunity	921	5-5		
Arcing Currents	IAAI	42	43	3	Arson Immunity	IAAI	36	40	4
Arcing Ground Fault	IAAI	26	44	4	Arson Immunity	IAAI	44	40	2
Arcing in Fires	921	14-5.4			Arson Immunity Law	IAAI	22	42	2
Arcing Through Char	921	1-3			Arson Immunity Laws	Kirk	354		
Arcing, Auto	921	15-3.2.2			Arson Law	Kirk	346		
Arcs	IAAI	48	41	4	Arson Prevention	IAAI	6	42	2
Arcs, Contamination	921	14-4.4.5			Arson Reporting	921	5-5		

Keyword	Book	Section/ Page	Volume	Number
Baseboard Heaters	921	18-5.7		
Basswood	921	Table 3-3.1		
Batteries	921	15-2.2		
Batteries	921	18-5.2.3		
Battery Cable	IAAI	46	40	4
Battery, Auto	921	15-3.2		
Battery, Detector	IAAI	18	43	1
Baum, Kevin	IAAI	8	44	1
Bead	921	1-3		
Beaded Conductor	921	14-5.4		
Beaded Wire	921	14-7.6		
Beaded Wires	IAAI	36	44	2
Beading of Wires	Kirk	139		
Beading/Wires	IAAI	22	44	3
Beads on Conductors	921	14-5.2		
Beads, Gas Content	IAAI	21	44	4
Beads-Copper	IAAI	40	44	4
Beavis & Butthead	IAAI	40	44	2
Beco	IAAI	58	42	1
Bedsprings-Melted	IAAI	19	43	4
Beering, Peter S.	IAAI	33	41	3
Beering, Peter S.	IAAI	51	41	2
Beland, Bernard	IAAI	43	44	2
Beland, Bernard	IAAI	36	40	2
Beland, Bernard	IAAI	40	44	4
Beland, Bernard	IAAI	43	44	4
Beland, Bernard	IAAI	63	44	3
Beland, Bernard	IAAI	39	44	4
Beland, Bernard	IAAI	20	44	4
Beland, Bernard	IAAI	27	45	1
Beland, Bernard	IAAI	31	44	4
Beland, Bernard	IAAI	61	43	1
Beland, Bernard	IAAI	26	44	1
Beland, Bernard	IAAI	42	43	4
Beland, Bernard	IAAI	30	43	2
Beland, Bernard	IAAI	35	43	2
Beland, Bernard	IAAI	55	43	4
Beland, Bernard	IAAI	44	44	4
Beland, Bernard	IAAI	61	42	3
Bending	921	4-9		
Benzene	921	Table 3-3.4		
Benzene	921	Table 3-3		
Benzene	Kirk	257		
Benzine	Kirk	257		
Berman Mattress	IAAI	12	45	1
Bernoulli Effect	Kirk	78		
Berrin, Elliott R.	IAAI	56	41	2
Best Value	IAAI	8	44	1
Bevis & Butthead	IAAI	64	44	3
Black Hole	IAAI	18	43	4
Black Hole	IAAI	56	44	3
Black Oil	921	Table 14-8.2.1		
Black Oxide	921	4-7		
Black Powder	IAAI	35	44	2
Black Powder	Kirk	238		
Black Powder	Kirk	258		
Black Powder	Kirk	240		
Black Smoke	921	3-6		
Black & Decker	IAAI	58	40	1
Blackpowder	Kirk	83		
Blackpowder	Kirk	341		
Blankets, Electric	IAAI	39	41	2
Blast Front Shape	921	13-4.1.3		
Blast Pattern	Kirk	243		

Keyword	Book	Section/ Page	Volume	Number
Brown, Carrie	IAAI	10	44	4
Brown, Lloyd R.	IAAI	36	44	2
Brown, William	IAAI	11	44	4
Brushfire	IAAI	55	43	3
Buddy System	IAAI	57	44	1
Bug Killer	IAAI	56	40	1
Bug Killers	IAAI	60	40	4
Building Contents	921	4-16.3		
Building Collapse	921	4-17.7.2		
Building Electric Systems	921	14-3		
Bukowski, Richard W.	IAAI	36	42	3
Bulbs, Auto	921	15-3.2.3		
Bulb, Incandescent	921	18-5.8		
Bundled Wires	921	14-3.6. 2.1		
Burn Pattern	Kirk	109		
Burn Patterns	921	3-7.2		
Burn Rate, Cigarettes	Kirk	84		
Burn Time	921	4-5.5		
Burnett, Guy E.	IAAI	14	42	4
Burning Rate	921	1-3		
Burning Velocity	921	13.2.2.1		
Burning-Defined	Kirk	347		
Butane	Kirk	253		
Butane	Kirk	41		
Butanone	Kirk	256		
Buxton, William N.	IAAI	38	44	2
Bystanders	921	10-2.6		
Cabinets, Electrical	921	14-3.6. 3.1		
Cable Tray	921	14-3.6. 2.1		
Cadweld	Kirk	260		
Calcination	921	4-12		
Calcium Carbonate	IAAI	35	41	4

Keyword	Book	Section/ Page	Volume	Number
Camara vs. San Francisco	Kirk	351		
Camera/Cold	IAAI	12	40	2
Can Opener	921	18-6.4		
Canary Islands	IAAI	14	42	2
Candle	IAAI	54	44	3
Candle Effect	Kirk	305		
Cans	921	9-6.1		
Cans, Evidence	Kirk	147		
Cans, Explode	Kirk	137		
Capillary Columns	IAAI	50	44	2
Capillary Columns	Kirk	275		
Carbon Dioxide	Kirk	9		
Carbon Disulfide	Kirk	256		
Carbon Monoxide	921	3-5.3.2		
Carbon Monoxide	IAAI	55	41	1
Carbon Monoxide	IAAI	43	43	1
Carbon Monoxide	Kirk	310		
Carbon Path	IAAI	35	42	2
Carbon Path	IAAI	36	44	2
Carbonization/Insulation	Kirk	202		
Carburetor	921	15-5.2.3		
Carburetor	921	15-3.1		
Cardoulis, John N.	IAAI	6	42	1
Cargo Area, Auto	921	15-5.13		
Carney, Billy	IAAI	63	40	4
Carpet	921	9-2.2		
Carpet Samples	IAAI	38	40	3
Carpets	921	4-17.7.2		
Carpets	921	4-16.1.3		
Carpet/Rugs	Kirk	222		
Cartridge Fuses	921	14-3.3.1		
Cascade Explosions	921	13-8.4		

Keyword	Book	Section/ Page	Volume	Number
Cast Iron	921	Table 4-8		
Cast Iron	Kirk	131		
Catalytic Convertor	921	15-3.3		
Catalytic Convertor	Kirk	173		
Catalytic Convertor	Kirk	165		
Catalytic Oxidation	Kirk	37		
Cause	921	5-6.1		
Cause Classification	921	12-2		
Cause Determination	921	Chapter 12		
Cause Elimination	Kirk	343		
Cause of Fire	921	12-5		
Cause (See Fire Cause)	921	1-3		
Ceiling Damage (Inside)	921	4-16.1.3		
Ceiling Height	921	3-5.4.2		
Ceiling Layer	921	1-3		
Ceiling Layer	921	Figure 3-5.3.2-(b)		
Ceiling Layer Temperature	921	Figure 3-5.3.1(b)		
Ceilings	921	3-5.3.1		
Cellulose Insulation	IAAI	36	41	2
Ceramic Samples	IAAI	39	40	3
Ceramic Tile	921	3-6		
Certainty of Opinions	921	12-6		
Chain of Custody	921	5-3.2.1		
Chain of Custody	921	9-9		
Chain of Custody	Kirk	151		
Chain of Custody	Kirk	355		
Chain of Evidence	Kirk	151		
Chain of Evidence	Kirk	355		
Chain Reaction	Kirk	22		
Chair	921	Table 3-4		
Chaparral	Kirk	155		
Char	921	4-5.3.3		
Char	921	4-5.3		
Char	921	4-5.4		
Char	921	4-5.1		
Char	921	4-5		
Char	921	4-5.3.2		
Char	921	4-7		
Char	921	4-5.2		
Char	921	1-3		
Char	IAAI	12	41	2
Char Blisters	921	1-3		
Char Depth	Kirk	117		
Char Grid Diagram	921	11-2.4		
Char Rate	Kirk	117		
Char (Misconceptions)	921	4-5.5		
Charcoal	921	Table 3-3.5		
Charcoal	IAAI	16	44	3
Charcoal	Kirk	131		
Charcoal Adsorption	IAAI	50	44	2
Charcoal Lighter	IAAI	61	44	4
Charcoal Lighter	IAAI	46	42	1
Charcoal Sampling	Kirk	278		
Charcoal Trap	Kirk	277		
Charcoal/Water	IAAI	17	44	3
Charm Glow	IAAI	56	40	1
Charmglow	IAAI	60	40	4
Charring	921	4-17.6		
Char, Arcs	921	14-4.4.4		
Char, Conductive	921	14-5.4		
Char, Dull	Kirk	119		
Char, Shiny	Kirk	119		
Checkered Glass	IAAI	57	44	3
Chemical Engineer	921	6-5.4		

Keyword	Book	Section/ Page	Volume	Number
Chemical Explosions	921	13-2.2		
Chemical Explosions	921	13-4.3		
Chemical Ignition	Kirk	341		
Chemical Incendiaries	IAAI	36	41	4
Chemical Oxidizers	921	3-1.1.2		
Chemical Reactions	Kirk	70		
Chemist	921	6-5.4		
Chemistry of Combustion	921	3-1		
Child Deaths	IAAI	51	40	1
Children's Sleepware	Kirk	222		
Chimney Fires	IAAI	21	42	3
Chimneys	Kirk	79		
China Pyrotechnics	IAAI	13	45	1
Chloracne	IAAI	33	41	2
Chlorate	Kirk	260		
Chlorates	Kirk	259		
Chlorine	921	3-1.1.2		
Chlorine Tablets	Kirk	341		
Chlorine Tablets	Kirk	286		
Christmas Lights	IAAI	43	41	1
Christmas Trees	921	Table 3-4		
Chromatograph	IAAI	52	41	4
Chromium	921	Table 4-8		
Cigarette	921	Table 3-3		
Cigarette Identification	Kirk	168		
Cigarette Lighter	IAA1	17	44	2
Cigarette-Temperature	IAAI	27	44	4
Cigarettes	Kirk	84		
Cigarettes	Kirk	339		
Cigarettes & Auto	921	15-3.5		
Cigarettes, Autos	Kirk	175		
Cigarettes-Ignite Gases	Kirk	236		

Keyword	Book	Section/ Page	Volume	Number
Cigarette, Fire Safe	IAAI	19	42	1
Cigarette Ignition Resistance of Furniture	921	9-10.2.14		
Cigarette Ignition Resistance of Furniture	921	9-10.2.15		
Circuit Breaker	IAAI	36	43	3
Circuit Breaker & Appliances	921	18-5.2.4		
Circuit Breakers	921	14-3.5.3		
Circuit Breakers	IAAI	42	41	4
Circuit Breakers	IAAI	61	42	2
Circuit Breakers	IAAI	52	43	2
Circuit Breakers	Kirk	199		
Circuit Breaker, Heat	921	18-5.2.4		
Circuit Breaker/GFCI	921	14-3.5.3.3		
Circular Pattern	921	14-17.7		
Circular Patterns	921	4-17.8		
Circumstantial Evidence	Kirk	347		
Circumstantial Evidence	Kirk	348		
Civil Litigation	921	5-6		
Classification of Cause	921	12-2		
Clean Burn	921	4-11		
Clean Burn	921	1-3		
Clean Burn	921	4-7		
Cleveland Open Cup	921	9-10.2.7		
Cleveland Open Cup	Kirk	270		
Clinker, Hay	Kirk	90		
Clothes Dryer	921	18-6.13		
Clothes Dryer	Kirk	207		
Clothes Dryers	IAAI	6	42	1
Clothes Iron	921	18-6.12		
Clothing Samples	IAAI	39	40	3
Clothing & Static	921	14-8.2.8		
Clothing, Safety	921	10-1.2		
Cloutier, Jean-Claude	IAAI	10	44	4

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Copper-Corrosion	IAAI	42	44	4	Crazing	921	4-13.1		
Copper-Fire	IAAI	40	44	4	Cremation	Kirk	304		
Copper-Melt	IAAI	27	44	4	Creosote	IAAI	21	42	3
Copper-Melting	IAAI	40	44	4	Criminal Act	921	5-4.1.2		
Copper-Nickel Alloy	921	Table 3-3			Criminal Act	921	5-4.2		
Copper/Aluminum	IAAI	61	43	1	Criminal Prosecution	921	5-4		
Copper/Chlorine	IAAI	58	42	3	Criminal Search Warrant	921	5-2.3.4		
Copper/Melted	IAAI	58	40	2	Critical Diameter	Kirk	237		
Copper/Welding	IAAI	61	43	1	Critical Radiant Flux	921	4-16.1.3		
Corner Burn Out	Kirk	114			Critical Radiant Flux	921	9-10.2. 20		
Corner Effects	921	3-5.4.3			Critical Temperature	Kirk	239		
Corners, Burning	921	3-3.1			Cronk, Peter	IAAI	26	43	3
Coronado, Rodney	IAAI	37	44	4	Crowd Photographs	921	8-2.5.2		
Corrosiveness	Kirk	287			Crowning	Kirk	155		
Corry, Bob	IAAI	21	42	3	CS-191-53	Kirk	222		
Corry, Robert A.	IAAI	36	41	1	Current	Kirk	192		
Cosmic Eruption	IAAI	13	45	1	Current Capacities	Kirk	197		
Cotton	Kirk	219			Current Limiters	IAAI	43	44	2
Cotton Balls	921	9-5.3.1			Current vs. Electrical Flow	921	14-2.5		
Cotton Chair	921	Table 3-4			Current vs. Water Flow	921	14-2.2		
Cotton Mattress	921	Table 3-4			Current/Temperature	Kirk	197		
County Assessor	921	7-5.2.3			Custodial Setting	921	5-3.4.1		
County Clerk	921	7-5.2.2			Custody	Kirk	151		
County Coroner	921	7-5.2.5			Cut	Kirk	257		
County Government	921	7-5.2			Cyanide	Kirk	319		
County Recorder	921	7-5.2.1			Cyclohexanone	Kirk	257		
County Sheriff's Department	921	7-5.2.6			Damage Analysis, Explosion	921	13-17.2		
County Treasurer	921	7-5.2.4			Damage Assessment	921	11-2		
Cracks in Floor	921	4-16.1.4			Damage Effects, Explosion	921	13-12. 3.1		
Crazed Glass	IAAI	57	44	3	Damage Table	Kirk	247		
Crazed Glass	IAAI	19	43	4	Damage vs. Origin	921	3-7.2		
Crazing	921	4-13.1			Damaged Items & Structures	921	13-17. 2.4		

Keyword	Book	Section/ Page	Volume	Number
Detonation	921	13.2.2.1		
Detonation	Kirk	229		
Detonation	Kirk	237		
Detonation	Kirk	241		
Detonation Temperatures	921	13-4.3		
Dextron II	921	Table 15-2.1		
Diagram (Char)	921	4-5.3.1		
Diagrams	921	5-3.2.1-.1		
Dielectric Withstand Voltage	921	9-10.2.-29		
Diesel	921	Table 15-2.1		
Diesel Fueled Vehicles	921	15-5.1.2		
Diethyl Ether	Kirk	256		
Diethylamine	Kirk	258		
Dietz, William	IAAI	33	41	4
Diffused Phase Explosion	Kirk	237		
Diffuse-Phase Explosion	Kirk	230		
Diffusion	Kirk	41		
Dillon, Barry	IAAI	58	40	2
Dimethylamine	Kirk	258		
Ding, Mr.	IAAI	63	42	1
Direct Evidence	Kirk	348		
Dirt in Electrical Equipment	IAAI	37	44	2
Dirt Samples	IAAI	37	40	3
Dirt/Electricity	IAAI	62	42	2
Dirt/Electricity	IAAI	60	42	4
Disabled Devices	921	11-6.1		
Disassemble Appliance	921	18-4.4		
Disc Furnace	IAAI	56	40	1
Dishwasher	921	18-6.6		
Dishwasher	IAAI	56	40	1
Disposable Gloves	921	9-4.2		
Documentary Evidence	921	5-3.2.2		
Documents	Kirk	267		
Documents/Collection	IAAI	39	41	4
Dogs	IAAI	22	45	1
Dogs-Arson	IAAI	50	43	3
Door Bolts	Kirk	271		
Door Char	921	3-7.2		
Door Closed	921	3-7.2		
Doors & Windows	921	11-5.3		
Door, Open or Closed	921	11-5.3		
Double Damages	921	5-6.1		
Doughnut Pattern	921	4-17.7.3		
Downing, Mark	IAAI	53	43	3
Drawing Symbols	921	8-4.4		
Drawing Types	921	8-4.2		
Drawing Variation	921	8-4.6.1		
Drawings	921	8.4		
Drawings, Architectural	921	8-4.6		
Drawings, Engineering	921	8-4.6		
Drawings, Minimum	921	8-4.5		
Drop Down	921	1-3		
Drop Down	921	4-16.4.2		
Drug Laboratories	Kirk	261		
Drug Samples	Kirk	150		
Dryer Hose	IAAI	45	44	4
Dryer, Clothes	921	18-6.13		
Drying/Air	IAAI	50	40	3
Due Process	IAAI	22	44	3
Dunn, R. Rogge	IAAI	25	41	4
Dust Concentration	921	13-9.2		
Dust Explosion	Kirk	234		
Dust Explosions	921	13-7.3		
Dust Explosions	921	13-9		

Keyword	Book	Section/ Page	Volume	Number
Exhaust System	921	15-5.3		
Exigent Circumstance	921	5-2.3		
Exigent Circumstance	921	5-2.3.2		
Exothermic	Kirk	7		
Exothermic Reaction	921	3-1.1.4		
Exothermic Reactions	921	4-8.1		
Expert Testimony	921	5-7		
Expert Testimony	IAAI	25	41	4
Expert Witness	921	5-7.2		
Expert Witness	IAAI	35	42	4
Expert Witness	IAAI	33	41	3
Expert Witness	Kirk	358		
Expert-Deposition	IAAI	25	41	3
Expert/Lies	IAAI	21	44	3
Exploding Cans	Kirk	137		
Explosion	921	1-3		
Explosion	Kirk	119		
Explosion	Kirk	229		
Explosion Damage Analysis	921	13-17.2		
Explosion Damage Effects	921	13-12.-3.1		
Explosion Debris Analysis	921	13-17.-2.1		
Explosion Dynamics Analysis	921	13-14		
Explosion Effects	921	13-5		
Explosion Effects, Thermal	921	13-17-5		
Explosion Elements	921	13-1		
Explosion Evidence	921	11-5.4		
Explosion Fuel Source	921	13-15		
Explosion Fuel Source	921	13-13.-2.7		
Explosion Ignition Source	921	13-13.-2.8		
Explosion Origin	921	13-13.-2.6		
Explosion Type	921	13-13.-2.7		
Explosion Venting	921	13-8.2.6		
Explosions	921	Chapter 13		
Explosions	921	4-17.8		
Explosions-Combustion	921	13.2.2.1		
Explosions, Outdoor Vapor	921	13-11		
Explosion, Analyze Cause	921	13-17		
Explosion, Chemical	921	13-2.2		
Explosion, Ignition Source	921	13-16		
Explosion, Mechanical	921	13-2.1		
Explosion, Structural Damage	921	13-17.2.2		
Explosion, Time Line	921	13-17.1		
Explosion-Ignition Source	921	13-8.2.5		
Explosion-Space Volume	921	13-8.2.4		
Explosive	921	1-3		
Explosive Investigation	921	13-12		
Explosive Limits	IAAI	38	41	2
Explosive Limits	Kirk	38		
Explosive Material	921	1-3		
Explosive Residue	Kirk	250		
Explosives	921	13-12		
Explosives	921	13-6.1		
Explosives-Table	Kirk	242		
Exposed Surface	921	1-3		
Express	IAAI	49	41	1
Extension Cords	IAAI	56	43	2
Extension Cords	IAAI	23	42	1
Extension Power Strip	IAAI	59	40	1
Exterior Damage	921	11-5.5		
Exterior Examination	921	11-5		
Exterior Examination	921	11-3.3		
Exterior Fires	Kirk	141		
Exterior Search	Kirk	108		
External Surfaces	921	4-16.2		

Keyword	Book	Section/ Page	Volume	Number
Fire Propogation	921	1-3		
Fire Protection Engineering	921	6-5.5.1		
Fire Resistive	Kirk	97		
Fire Scene Reconstruction	921	1-3		
Fire Science & Engineering	921	6-5.5		
Fire Spread	921	1-3		
Fire Spread	IAAI	58	43	1
Fire Spread Scenario	921	11-8		
Fire Storm	Kirk	24		
Fire Temperature	IAAI	59	40	2
Fire Tetrahedron	921	3-1.1		
Fire Transfer	IAAI	42	40	3
Fire Triangle	Kirk	17		
Fire Wall, Automotive	921	15-5.10		
Fire-Definition	Kirk	16		
Fireball	Kirk	51		
Firefighter Deaths	IAAI	34	41	1
Firefighters, Interview	Kirk	106		
Firefighter-Death	IAAI	44	40	1
Firemen Deaths	IAAI	34	41	1
Firemen-Death	IAAI	28	41	2
Fireplace	Kirk	79		
Fireworks	IAAI	13	45	1
Fireworks	IAAI	41	41	1
Fireworks	IAAI	48	41	1
First Ignited	921	3-5.3.2		
First Material Ignited	921	3-7		
First Material Ignited	921	12-4		
Fish Meal	921	Table 3-3.5		
Fittings, Conduit	921	14-3.6.4		
Flame	921	1-3		
Flame Color	Kirk	62		
Flame Color	Kirk	315		
Flame Extension	921	3-1.1.2		
Flame Front	921	1-3		
Flame Height	921	3-5.5		
Flame Impingement	Kirk	27		
Flame Ionization Detector	Kirk	275		
Flame Length	921	3-5.4.3		
Flame Point	Kirk	36		
Flame Speed	921	13.2.2.1		
Flame Temperature	921	4-8.1		
Flame Temperature, Wood	Kirk	51		
Flameover	921	3-5.3.2		
Flameover	921	3-5.3.2		
Flameover	921	1-3		
Flaming Combustion	921	3-1.1.4		
Flammable	921	1-3		
Flammable Gases, Density	Kirk	43		
Flammable Limit	921	1-3		
Flammable Limits	921	3-1.1.2		
Flammable Limits	IAAI	38	41	2
Flammable Limits	Kirk	38		
Flammable Liquid	921	4-6		
Flammable Liquid	921	4-17.7.3		
Flammable Liquid	921	4-6.1		
Flammable Liquid	921	4-18.1		
Flammable Liquid	921	1-3		
Flammable Liquid	IAAI	39	42	1
Flammable Liquid	Kirk	114		
Flammable Liquids	921	4-17.7.2		
Flammable Liquids	921	4-17.2.1		
Flammable Liquids	921	4-17.2		
Flammable Liquids	921	3-6		

Keyword	Book	Section/ Page	Volume	Number
Flammable Liquids	Kirk	124		
Flammable Range	921	3-1.1.2		
Flammable Residues	IAAI	16	41	3
Flammability of Textiles	921	9-10.13		
Flammability of Aerosols	921	9-10.2.-17		
Flammability of Floor Covering	921	9-10.2.-16		
Flanking Fire	Kirk	155		
Flares	Kirk	83		
Flares	Kirk	259		
Flares	Kirk	168		
Flash Fire	921	4-19		
Flash Fire	921	1-3		
Flash Fires	921	4-19.2		
Flash Point	921	3-3.2		
Flash Point	IAAI	41	42	1
Flash Point	IAAI	16	40	3
Flash Point	IAAI	58	40	3
Flash Point	Kirk	270		
Flash Point	Kirk	35		
Flash Point of a Liquid	921	1-3		
Flash Point, Closed	921	9-10.2.8		
Flash Point, Closed	921	9-10.2.-10		
Flash Point, Closed	921	9-10.2.6		
Flash Point, Open	921	9-10.2.7		
Flash Point, Open	921	9-10.2.9		
Flashback	Kirk	29		
Flashover	921	Figure 3-5.3.2 (d)		
Flashover	921	3-5.3.2		
Flashover	921	3-5.4.3		
Flashover	921	3-6		
Flashover	921	3-2.2		
Flashover	921	4-17.7.2		

Keyword	Book	Section/ Page	Volume	Number
Flashover	921	1-3		
Flashover	921	4-16.1.4		
Flashover	921	3-4		
Flashover	921	4-19.1		
Flashover	921	3-5.3.2		
Flashover	921	4-16.1.3		
Flashover	IAAI	53	43	1
Flashover	Kirk	28		
Flashover Patterns	921	3-7.3		
Flashpoint	IAAI	61	40	4
Flashpoint	IAAI	59	41	1
Flashpowder	Kirk	286		
Flashpowder	Kirk	259		
Flashpowder	Kirk	341		
Flex Duct	IAAI	45	44	4
Flexible Cable	IAAI	36	43	2
Floating Neutral	IAAI	31	44	4
Floor Covering Systems	921	9-10.2. 20		
Floor Covering, Flammability	921	9-10.2. 16		
Floor Penetration	Kirk	111		
Flooring Samples	IAAI	38	40	3
Floors	921	4-16.1.3		
Floors, Holes	921	4-3.3		
Flour	921	9-5.3.1		
Fluorescent Dyes	IAAI	9	40	2
Fluorescent Lights	921	18-5.8		
Fluorescent Lights	921	18-5.5		
Fluorescent Lights	IAAI	4	42	1
Fluorelastomers	IAAI	27	42	4
Flux for Flashover	Kirk	28		
Flux Level	921	3-5.3.2		
Foam Rubber	921	Table 3-3.5		

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Fuel/Air Mix vs. Damage	921	13-8.2			Futons	IAAI	59	40	4
Fugitive Gases	921	13-8.3			Galvanized Steel	921	4-7		
Fumes, Toxic	IAAI	26	40	3	Gardner-Pacific	IAAI	49	41	1
Fun World	IAAI	44	41	1	Garment Steamer	IAAI	42	41	1
Fundamental Velocity	921	13.2.2.1			Gas	921	1-3		
Funding Investigations	IAAI	50	42	4	Gas Appliances	Kirk	73		
Furnace	IAAI	54	40	1	Gas Appliances	Kirk	318		
Furniture Springs	921	4-14			Gas Backfire	Kirk	75		
Furniture, Time to Ignite	Kirk	85			Gas Burns Upwards	Kirk	74		
Furniture, Upholstered	IAAI	19	42	1	Gas Chromatograph	IAAI	50	44	2
Furniture/Foam	IAAI	40	40	2	Gas Chromatograph	Kirk	273		
Fuse Blown	IAAI	50	41	4	Gas Chromatography	921	4-17.7.2		
Fuse Color	IAAI	36	40	2	Gas Chromatography	921	9-10.2.1		
Fuse Curves	IAAI	42	43	3	Gas Chromatography	IAAI	63	42	4
Fuse Face	IAAI	36	40	2	Gas Explosions	Kirk	230		
Fuse Melting	Kirk	199			Gas Indicator	921	4-17.7.2		
Fuse Open Time	IAAI	42	43	3	Gas Jet	921	4-3.3		
Fuse Panels	921	14-3.3.1			Gas Line Breakage	Kirk	72		
Fused Copper	Kirk	139			Gas Migration	921	13-8.3		
Fuses	Kirk	285			Gas Migration	921	13-8.4		
Fuses	Kirk	259			Gas Odorant	921	13-8.5		
Fuses	IAAI	36	40	2	Gas Odorants	Kirk	72		
Fuses	IAAI	25	44	4	Gas Powered Vehicles	921	15-5.1.3		
Fuses	Kirk	339			Gas Pumps-Cars	IAAI	59	43	3
Fuses	Kirk	198			Gas Volume, Formula	Kirk	44		
Fuses, Screw type	921	14-3.3.1			Gas & Static	921	14-8.2.5		
Fuses, Vehicle	IAAI	37	43	1	Gaseous Fuels	921	15-2.2		
Fuse, Appliance	921	18-5.2.4			Gaseous Samples	921	9-5.4		
Fuse, Vaporizing	921	18-5.2.4			Gases Present in Fires	921	9-10.2.23		
Fuse-Blacked Face	IAAI	53	43	2	Gases, Ignition	921	3-3.3		
Fusion Current	Kirk	197			Gasoline	921	Table 3-3		
Futons	IAAI	61	42	1	Gasoline	921	Table 15-2.1		

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Hart, John	IAAI	28	41	2	Heat Release Rate	921	3-5		
Hate Fires	Kirk	327			Heat Release Rates	921	3-7.2		
Hay	921	Table 3-3.5			Heat Release Rates	921	9-10.2. 24		
Hay	Kirk	89			Heat Retention	IAAI	16	44	3
Hay, Clinker	Kirk	90			Heat Shadowing	921	4-15.1		
Hay, Time to Ignite	Kirk	90			Heat Source	921	11-2.3		
Hazard	921	1-3			Heat Tape	IAAI	39	44	4
Hazard 1	IAAI	36	42	3	Heat Tapes	IAAI	9	42	1
Hazardous Materials	921	9-8.2.2			Heat Transfer	921	3-2		
Hazardous Waste	IAAI	33	41	2	Heat Transfer	921	3-2.1		
Hazards-Safety	921	10-1.3			Heat Transfer	921	3-3		
Hazards/Fire Scenes	IAAI	22	41	3	Heater, Portable	IAAI	56	40	1
Head Space	Kirk	277			Heating Appliances	IAAI	39	41	2
Health Hazards	IAAI	57	44	1	Heating Elements	921	18-5.7		
Health & Safety	921	10-1.4			Heating Equipment	Kirk	315		
Heat	921	3-2			Heatpipe	IAAI	12	45	1
Heat	921	1-3			Heavy Timber	Kirk	97		
Heat	921	3-1.1.3			Height of Burn	921	4-16.4		
Heat Capacity	921	3-2.1			Hemlock	921	Table 3-3.1		
Heat Detectors	921	3-5.3.1			Higgins, Mike	IAAI	57	43	3
Heat Flux	921	1-3			High Density Materials	921	3-2.1		
Heat Level	Kirk	112			High Explosive	921	1-3		
Heat Machine	IAAI	41	41	1	High Explosive	Kirk	240		
Heat of Combustion	921	9-10.2.- 12			High Explosives	921	13-12.2		
Heat of Combustion	Kirk	44			High Order	Kirk	241		
Heat of Ignition	921	1-3			High Order Explosion	921	1-3		
Heat Release	921	Table 3-4			High Order Explosion	921	13-3		
Heat Release	921	3-5.3.2			High Order Explosions	921	13-3.2		
Heat Release	921	3-5.4.1			High Resistance	IAAI	44	41	4
Heat Release Rate	921	3-5.5			High Resistance Arc	IAAI	62	42	2
Heat Release Rate	921	1-3			High Resistance Arc	IAAI	60	42	3
Heat Release Rate	921	3-4			High Resistance Fault	921	15-3.2.1		

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
High Resistance Ground	IAAI	40	43	2	Hydrocarbon Vapors	921	3-5.3.2		
High Resistance Short	IAAI	37	43	1	Hydrocarbons	921	4-17.7.2		
High Rise	IAAI	15	44	1	Hydrofluoric Acid	IAAI	27	42	4
High Resistance Arc	IAAI	61	42	4	Hydrogen	921	Table 15-2.2		
High Voltage Cable	IAAI	63	40	4	Hydrogen	921	3-1.1.2		
Holes	921	4-17.7.3			Hydrogen	921	15-5.7		
Holes	921	3-7.2			Hydrogen	921	15-2.2		
Holes	921	4-3.3			Hydrogen	Kirk	254		
Holes in Floor	921	4-16.1.4			Hydrogen Chloride	921	14-3.6. 2.1		
Holes in Floors	921	3-7.2			Hydrogen Cyanide	921	3-6		
Holes in Floors	921	3-7.4			Hydrogen Cyanide	IAAI	26	40	3
Hood, William	IAAI	11	44	4	Hydrogen Fluoride	IAAI	27	42	4
Hood, William	IAAI	14	44	2	Hydrogen Gas	Kirk	173		
Hooten, David B.	IAAI	8	45	1	Hypalon	IAAI	57	43	4
Hot Conductor	921	14-3.7.2			Hypergolic	Kirk	286		
Hot Metals	Kirk	81			Hypothesis	921	2-3.5		
Hot Objects	Kirk	69			Hypothesis	921	2-3.6		
Hot Spots	921	18-4.1			Icove, David J.	IAAI	44	40	2
Hourglass	921	3-7.1			Identification of Evidence	921	9-7		
Hourglass Pattern	921	4-17.3			Identify Explosion	921	13-13. 2.1		
Huff, Timothy G.	IAAI	24	43	4	Ignitable Liquid	921	1-3		
Human Combustion	Kirk	305			Ignition	921	3-3		
Human Factor	IAAI	35	43	4	Ignition	921	1-3		
Human Injury Criteria	921	Table 13-13.-3.1			Ignition Energy	921	1-3		
Human Remains	Kirk	298			Ignition Energy & Static	921	14-8.4		
Human Torch	Kirk	309			Ignition Energy, Dust	921	13-9.5		
Humans & Static	921	14-8.2.7			Ignition Factor	921	12-5		
Humidity	Kirk	30			Ignition of Gases	921	3-3.3		
Humidity & Static	921	14-8.5.1			Ignition of Liquids	921	3-3.2		
Huntsman	IAAI	49	41	1	Ignition Point	IAAI	42	42	1
Hydrocarbon Detection Canine	IAAI	22	45	1	Ignition Point	Kirk	37		
Hydrocarbon Fuels	921	3-6			Ignition Point, Hay	Kirk	89		

Keyword	Book	Section/ Page	Volume	Number
Inventory-Arson	IAAI	44	40	1
Inventory/Estimates	IAAI	14	40	2
Inverted Cone Pattern	921	4-17.2.1		
Inverted Cone Pattern	921	4.17.2.3		
Inverted Cone Pattern	921	4-17.2		
Investigating Static	921	14-8.7		
Investigation & Suppression	921	10-2.1		
Investigations	Kirk	93		
Investigation/Quality	IAAI	14	40	3
Investigator/Private	IAAI	60	42	1
IR	Kirk	281		
Iron	921	4-8.2		
Iron	921	Table 4-8		
Iron	IAAI	56	40	1
Irons	IAAI	42	41	1
Iron, Electric	921	18-6.12		
Irregular Patterns	921	17-2.6.3		
Irregular Patterns	921	4-17.8		
Irregular Patterns	921	4-17.7.2		
Isner, Michael S.	IAAI	56	42	2
Isochar	921	1-3		
Isochars	921	11-2.4		
Jacobs, Stewart	IAAI	50	43	3
Jenkins, Tamara	IAAI	15	44	2
Jennings, Michael	IAAI	8	42	1
Jerries, Eric	IAAI	22	41	4
Jimenez, Luis M.	IAAI	11	44	2
Johnson, Ken	IAAI	10	44	4
Jones, Nolan	IAAI	50	40	3
Jones, W. R.	IAAI	10	44	4
Jones, L. L.	IAAI	35	44	2
JP-4	921	Table 3-3		
Julia, Joseph	IAAI	35	43	3
Junction Boxes	921	14-3.6. 3.3		
Junghans, Frank	IAAI	58	40	3
Junghans, Frank	IAAI	38	41	2
Junghan, Frank	IAAI	59	41	1
Junghan, Frank	IAAI	63	41	3
Junghan, Frank	IAAI	61	40	4
Juvenile Firesetter	IAAI	27	43	3
Juvenile Law	IAAI	28	44	2
Juvenile/Arson	IAAI	14	40	2
J. C. Penny	IAAI	42	41	1
K-Mart	IAAI	40	41	1
Kamman, B. K.	IAAI	22	44	4
Kapak	IAAI	22	43	1
Kapok	Kirk	219		
Katz, Sheryl R.	IAAI	21	44	3
Kaufman, George	IAAI	39	42	2
Keller, Paul K.	IAAI		44	3
Kent Decision	IAAI	28	44	2
Kerosene	921	Table 3-3		
Kerosene	921	Table 15-2.1		
Kerosene	921	Table 3-3.4		
Kerosene	921	Table 14-8.2.1		
Kerosene	IAAI	55	41	1
Kerosene	Kirk	46		
Kerosene	Kirk	115		
Kerosene Heater	IAAI	54	41	1
Kerosene Heaters	IAAI	16	40	3
Kerosene Heaters	IAAI	44	41	1
Kerosene/Evaporation	IAAI	21	40	3
Kerosene/Gasoline	921	Table 3-4		
Ketone	Kirk	47		

Keyword	Book	Section/ Page	Volume	Number
Melted Copper	IAAI	19	43	4
Melted Copper	IAAI	58	40	2
Melted Metals	921	15-2.3		
Melted Metals	IAAI	58	40	2
Melted Solids	921	4-17.8		
Melted Steel	IAAI	19	43	4
Melting	921	4-9		
Melting	921	4-3.2		
Melting Conductors	921	14-6.2		
Melting Copper	Kirk	213		
Melting of Materials	921	4-8		
Melting Points	Kirk	131		
Melting Temperatures	921	Table 4-8		
Melting Temperatures	921	4-8		
Melting-Copper	IAAI	40	44	4
Mercaptan	921	13-8.5		
Mercaptan	Kirk	254		
Mertens, John M.	IAAI	34	44	4
Metal Cans	921	9-6.1.1		
Metal Distortion	921	4-20.2		
Metal Splatter	921	18-5.7		
Metals, Burning	921	4-8.1		
Metals, Hot	Kirk	81		
Metals, Melting	921	4-8.2		
Metal-Vaporized	IAAI	42	43	4
Meter Base	921	14-3.1.2		
Methane	921	Table 3-3.4		
Methane	Kirk	45		
Methane	Kirk	41		
Methane	Kirk	253		
Methanol	921	Table 3-3		
Methanol	921	Table 3-3.4		

Keyword	Book	Section/ Page	Volume	Number
Methanol	921	Table 15-2.1		
Methanol	Kirk	256		
Method of Entry	921	5-2.3		
Methyl Alcohol	Kirk	255		
Methyl Alcohol	Kirk	149		
Methyl Ethyl Ketone	921	Table 3-3.4		
Methyl Ethyl Ketone	Kirk	256		
Meyer, Earl N.	IAAI	15	40	3
Michaelson, Dennis	IAAI	21	44	3
Michigan vs. Clifford	921	5-2.3.3		
Michigan vs. Clifford	Kirk	352		
Michigan vs. Tyler	921	5-2.3.2		
Michigan vs. Tyler	Kirk	351		
Micromar	IAAI	41	41	1
Microwave Oven	921	18-6.7		
Micro-Mini Motorhome	IAAI	49	41	1
Midkiff, Charles R.	IAAI	22	43	1
Midkiff, Charles R.	IAAI	21	44	3
Midkiff, Charles R.	IAAI	42	41	2
Midkiff, Charles R.	IAAI	62	44	4
Midkiff, Charles R.	IAAI	45	41	2
Midkiff, Mr.	IAAI	63	42	1
Miller, Leroy	IAAI	15	44	2
Mincey vs. Arizona	Kirk	353		
Minimum Ignition Energy	921	13-9.5		
Minimum Ignition Energy	921	13-8.1		
Mirage of Elkhart	IAAI	49	41	1
Miranda Rule	921	5-3.4.1		
Mirrors	Kirk	165		
Misdemeanor	921	5-4.1.1		
Mist of Liquid	921	15-2.1		
Mists	921	3-3.2		

Keyword	Book	Section/ Page	Volume	Number
Photographic Survey	921	9-8.2		
Photographs	921	5-3.2.1-.1		
Photographs	IAAI	62	42	1
Photographs	IAAI	61	41	2
Photographs	IAAI	59	41	1
Photographs	Kirk	143		
Photography	921	8-2		
Photography	921	11-2.2		
Photography	IAAI	44	40	1
Photography	IAAI	12	40	2
Photography Tips	921	8-2.6		
Photograph Overlapping	921	8-2.4(b)		
Photograph Diagram	921	8-2.3.3		
Photograph Mosaics	921	8-2.3.2		
Photograph Preservation of Scene	921	8-2.1		
Photograph Sequential	921	8-2.3.1		
Photograph Techniques	921	8-2.3		
Photograph Types	921	8-2.2.7		
Photograph-Lighting	921	8-2.2.6		
Photo/Investigation	IAAI	60	40	3
Photo/Investigation	IAAI	58	41	3
Physical Evidence	921	9-2		
Pierre-Cardin	IAAI	43	41	1
Piloted Ignition Temperature	921	1-3		
Pine	921	Table 3-3.1		
Pine	921	Table 3-2.1		
Pine Shavings	921	3-4		
Pink Skin	Kirk	317		
Pipe Ashes	Kirk	86		
Pitted Contacts	921	18-5.3.2.2		
Pitted Contacts	IAAI	54	43	2
Placards	IAAI	25	41	2
Planning Investigation	921	6-1		
Plans & Drawings	921	16-19		
Plasma	IAAI	42	43	4
Plasma	IAAI	61	42	4
Plaster	921	4-12		
Plaster	921	4-9		
Plaster	921	4-3.2		
Plastic	921	1-3		
Plastic	921	3-6		
Plastic	921	4-16.1.4		
Plastic Bags	921	9-6.1.4		
Plastic Bag, Evidence	IAAI	22	43	1
Plastic Evidence Bags	Kirk	149		
Plastic Housings	921	18-5.1.4		
Plastic Ignition Test	921	9-10.2.27		
Plastic & Heat Release	921	15-2.3		
Plastic & Orientation	921	18-5.1.4		
Plastic (Melted)	921	4-17.8		
Plasticizer	921	4-16.1.4		
Plastics	921	4-10		
Plastics	921	Table 4-8		
Plastics	921	13-9		
Plastics	921	3-4		
Plastics	Kirk	58		
Plastic-Toxic	IAAI	8	43	1
Platinum	921	Table 4-8		
Play Pen	IAAI	16	44	2
Ployvinyl Chloride	921	Table 3-2.1		
Plug Damage, Electrical	921	18-5.2.1		
Plug Fuses	921	14-3.5		
Plume	921	1-3		
Plume	921	3-5.4.3		

Keyword	Book	Section/ Page	Volume	Number
Protected Area	Kirk	138		
Protected Areas	921	4-15.2		
Protected Areas	921	3-7.4		
Protecto Enterprises	IAAI	45	41	1
Proximate Cause	921	1-3		
Public Records	IAAI	23	40	2
Pugilistic Pose	Kirk	307		
Pump vs. Generator	921	14-2.4		
Purpose	921	1-2		
Purpose of Investigation	921	6-2.8		
Pusey, Willard L.	IAAI	9	44	4
Pusey, Willard L.	IAAI	11	44	4
PVC	921	Table 3-3.4		
PVC Chair	921	Table 3-4		
PVC Fume Ignition	921	14-5.6		
Pyroforic Carbon	IAAI	62	44	4
Pyrolysis Gases	921	3-5.3.2		
Pyrolitic	IAAI	21	42	3
Pyrolitic Carbon	IAAI	62	44	4
Pyrolysis	921	1-3		
Pyrolysis	Kirk	49		
Pyrolyze	Kirk	13		
Pyromania	Kirk	325		
Pyrophoric	Kirk	61		
Pyrophoric Carbon	IAAI	11	44	2
Pyrophoric Carbon	IAAI	32	44	4
Pyrophoric Carbon	Kirk	89		
Pyrophoric Carbon	Kirk	80		
Pyrophoric Carbon	Kirk	140		
Pyrophoric Carbon	Kirk	55		
Quantum Mowers	IAAI	22	43	3
Quartz	921	Table 4-8		
Raceways	921	14-3.6. 3.2		
Radiant Flux	921	3-7.3		
Radiant Heat	921	1-3		
Radiant Heat	Kirk	70		
Radiant Heat Flux	921	4-16.1.3		
Radiant Ignition	921	3-5.1		
Radiant Ignition	921	3-5.2		
Radiated Heat	921	4-11		
Radiated Heat	921	4-15.1		
Radiation	921	3-2.2		
Radiation	921	3-2		
Radiation	921	3-5.3.1		
Radiation	921	3-5.3.2		
Radiation	921	4-16.1.4		
Radiation	921	3-2.3		
Radiation	921	3-7.2		
Radiation	921	1-3		
Radiation	Kirk	25		
Radiation	Kirk	23		
Radio Shack	IAAI	40	41	1
Ranger	IAAI	49	41	1
Range, Electric, Gas	921	18-6.1		
Rate of Char	921	4-5.2		
Rate of Heat Release	921	1-3		
Rayon	Kirk	220		
RBR	IAAI	49	41	1
Reaction Rate-Doubles	Kirk	22		
Reaction Speed	Kirk	245		
Real Estate Industry	921	7-6.7		
Reasonable Time	921	5-2.3.2		
Recalls	IAAI	12	45	1
Receptacles-Contaminants	IAAI	55	43	2

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Schwartz, Bernard	IAAI	36	41	2	Self-Ignition	921	3-3.5		
Scientific Excavation	IAAI	50	44	4	Self-Ignition Temperature	921	1-3		
Scientific Method	921	2-3			Self-Sustained Chemical Reaction	921	3-1.1.4		
Scientific Method	921	1-3			Semi-Gelatin Dynamite	Kirk	238		
Scope	921	1-1			Serial Arson	IAAI	42	44	3
Screw in Fuses	921	14-3.3.1			Service Drop	921	14-3.1.1		
Search Pattern	921	13-13.1			Service Entrance Fault	921	14-5.4		
Search Pattern	Kirk	107			Service Entrance Overload	921	14-5.6		
Search Patterns	921	16-21			Service Equipment, Electric	921	14-3.1		
Search Warrant	921	5-2.3			Service Lateral	921	14-3.1.1		
Search Warrant	Kirk	349			Setaflash Tester	921	9-10. 2.10		
Search & Seizure	Kirk	348			Seufert, Frederick J.	IAAI	18	44	2
Search, Exterior	Kirk	108			Seufert, Mr.	IAAI	43	44	4
Sears-Mowers	IAAI	22	43	3	Seven Star	IAAI	4	42	4
Seat of Explosion	921	1-3			Sewer Gas	921	13-15		
Seated Explosion	921	1-3			Shape	921	4-3.2		
Seated Explosions	921	13-6			Shape of Blast Front	921	13-4.1.3		
Seated/Nonseated Explosion	921	13-13.-2.3			Sharp	IAAI	14	43	1
Seating Assemblies	IAAI	56	41	4	Shasta	IAAI	49	41	1
Second Item Ignited	921	3-5.3.2			Shefchick, Thomas	IAAI	60	42	4
Secondary Explosion	921	1-3			Shefchick, Thomas P.	IAAI		42	2
Secondary Explosions	921	13-8.4			Shiny Blisters	921	4-5.5		
Secretary of State	921	7-5.3.3			Ship-Explosion	IAAI	17	44	4
Securing the Scene	921	13-13.1			SHOCAP	IAAI	30	44	2
Security of Scene	921	6-2.7			Shock Wave	Kirk	246		
Security of Scene	Kirk	105			Shoes, Safety	921	10.1.2		
See vs. Seattle	Kirk	351			Short Circuit	921	1-3		
Seismic Effect	921	13-4.4			Short Circuit	921	14-4.4.3		
Self Employed	IAAI	9	41	1	Short Circuit	921	14-7.5		
Self-Heating	921	3-3.5			Short Circuit	IAAI	35	42	2
Self-Heating	921	1-3			Short Circuit	IAAI	51	44	3
Self-Ignition	921	1-3			Short Circuit	IAAI	48	41	4

Keyword	Book	Section/ Page	Volume	Number
Short Circuit	IAAI	25	44	4
Short Circuit Arcs	921	14-5.3		
Short Circuit Current	IAAI	43	44	2
Short Circuit, Current	921	14-4.5		
Short Circuit, Molten Metal	Kirk	82		
Shrapnel Effect	921	13-4.2		
Shuman, William R.	IAAI	52	43	2
Shur-Fire	IAAI	61	44	4
Silk	921	3-6		
Silk	Kirk	219		
Silver	921	Table 4-8		
Silver Rail Express	IAAI	42	41	1
Single Indicator	921	17-1		
Site Alteration	921	11-3.4		
Sixth Amendment	921	5-3.4.1		
Size of Incident	921	6-2.4		
Sketches	921	5-3.2.1-.1		
Sketches	Kirk	145		
Skin, Pink	Kirk	317		
Sleeving	IAAI	55	43	4
Sleeving	IAAI	55	43	2
Sleeving	IAAI	62	44	3
Sleeving	IAAI	37	44	2
Sleeving	Kirk	215		
Sleeving	Kirk	216		
Sleeving of Insulation	921	14-5.6		
Slides	IAAI	44	40	1
Sloping Sides	921	4-3.3		
Smart Kids	IAAI	4	42	1
Smith, David M.	IAAI	59	41	1
Smith, Frederick	IAAI	63	42	1
Smith, Frederick P.	IAAI	43	44	1

Keyword	Book	Section/ Page	Volume	Number
Smith, Raymond	IAAI	15	44	2
Smith, Tim	IAAI	9	41	1
Smoke	921	3-6		
Smoke	921	4-10		
Smoke	921	1-3		
Smoke Color	921	3-6		
Smoke Condensate	921	1-3		
Smoke Condensates	921	4-10		
Smoke Detector	IAAI	39	42	2
Smoke Detectors	921	3-5.3.2		
Smoke Detectors	921	3-5.3.1		
Smoke Explosion	921	13-7.4		
Smoke Explosion	921	1-3		
Smoke Explosion	921	13-10		
Smoke Explosion	Kirk	234		
Smoke Explosion	Kirk	29		
Smoke Level	Kirk	112		
Smoke Production	Kirk	64		
Smoke Production Rates	921	3-6		
Smoke Release Rates	921	9-10. 2.24		
Smoking	Kirk	84		
Smoking in Bed	Kirk	85		
Smoking & Auto	921	15-3.5		
Smoldering	921	1-3		
Smoldering	Kirk	339		
Smoldering	Kirk	29		
Smoldering Combustion	921	4-14		
Smoldering Combustion	921	3-1.1.4		
Smoldering (Holes)	921	4-3.3		
Snapper-Mowers	IAAI	22	43	3
Sniffers	Kirk	135		
Social Security Number	IAAI	12	42	2

Keyword	Book	Section/ Page	Volume	Number
Society of Fire Protection Engineers	921	7-6.2		
Sodium	Kirk	260		
Sodium	Kirk	341		
Sodium	Kirk	286		
Sodium Azide	IAAI	9	43	1
Soft Wood	921	Table 3-3.4		
Soil	921	4-7		
Soil Samples	IAAI	37	40	3
Soil Samples	Kirk	294		
Solder	921	Table 4-8		
Solder (Melting)	921	4-8		
Solenoids	921	18-5.4		
Solid Fuel	921	15-2.3		
Solid Gasoline	IAAI	48	42	2
Solid Samples	921	9-5.2.3		
Solo Investigation	921	10-1.1		
Solvent Extraction	Kirk	278		
Solvents	Kirk	255		
Somers, Charles	IAAI	25	41	3
Soot	921	3-6		
Soot	921	4-7		
Soot	921	4-10		
Soot	921	1-3		
Soot	921	3-5.3.2		
Soot	Kirk	19		
Soot Deposits	921	4-10		
Soot/Black	IAAI	55	44	3
Soot/Carbon Monoxide	Kirk	319		
Source of Heat	921	11-2.3		
Source of Heat of Ignition	921	12-3		
Sources of Information	Kirk	354		
Sources of Information	921	Chapter 7		

Keyword	Book	Section/ Page	Volume	Number
Space Heater	IAAI	41	41	1
Space Heater	IAAI	56	40	1
Space Heaters	921	18-6.8		
Space Maker	IAAI	58	40	1
Spalling	921	4-6		
Spalling	921	1-3		
Spalling	IAAI	63	42	1
Spalling	IAAI	26	44	1
Spalling	IAAI	45	41	2
Spalling	IAAI	43	44	1
Spalling	IAAI	42	41	2
Spalling	IAAI	62	44	3
Spalling	Kirk	121		
Spalling of Concrete	921	3-7.2		
Spalling (Misconceptions)	921	4-6.1		
Spalling/DeHaan	IAAI	44	44	1
Spalling/Discoloration	IAAI	46	44	1
Spalling/Lentini	IAAI	43	44	1
Spark	921	1-3		
Spark Promoters	921	14-8.2.2		
Spark Temperature	921	15-3.4		
Sparks	921	15-3.4		
Sparks	921	14-4.5		
Sparks	Kirk	340		
Sparks	Kirk	77		
Sparks	Kirk	205		
Sparks	Kirk	68		
Sparks, Distances	Kirk	78		
Sparks, Ignition Sources	921	14-4.5		
Sparks, Size of Particle	921	14-4.5		
Sparks, Wind	Kirk	78		
Spark, Electric	921	1-3		

Keyword	Book	Section/ Page	Volume	Number
Survey	Kirk	107		
Suspected-Opinion	921	12-6(d)		
Suspicious Fire Cause	921	12-2.4		
Suspicious Origin	921	5-5		
Swamp Gas	921	13-15		
Swan vs. Superior Court	Kirk	353		
Swept Headspace	Kirk	278		
Switch Loading, Static	921	14-8.2.3		
Switch vs. Valve	921	14-2.8		
Switch vs. Valve	921	14-2.3		
Switches	Kirk	209		
Switches, Appliances	921	18-5.3		
Switches, Electrical	921	14-3.9		
Switch, Off	IAAI	59	40	1
Symbols	921	8-4.4		
Systematic Approach	921	2-2		
Tables (Char Pattern)	921	4-17.7.1		
Tag	Kirk	270		
TAG Closed Cup	Kirk	36		
TAG Open Cup	921	9-10.2.9		
TAG Open Cup	Kirk	270		
Tagliabue Closed Cup	Kirk	270		
Tamarack	921	Table 3-3.1		
Tape Recorders	921	8-3.1		
Tapered Conductors	921	14-5.2		
Tapp, James	IAAI	15	44	2
Tar	921	3-6		
Target Fuel	921	3-5.3.2		
Tasaroom, Shalom	IAAI	45	40	4
Tatone, Kathy A.	IAAI	63	44	4
Tax-Deferred	IAAI	9	41	1
Team Concept	921	6-1		

Keyword	Book	Section/ Page	Volume	Number
Team Leader	921	16.5		
TEFAL	IAAI	41	41	1
Temperature	921	3-2		
Temperature	921	1-3		
Temperature Demarcation	921	4-8.1		
Temperatures (Ignition)	921	Table 3-3		
Temperatures, Cigarettes	Kirk	84		
Temperatures, Color	Kirk	19		
Temperatures, Fire	921	4-8.1		
Temperature, Ambient	Kirk	29		
Temperature-Measure	IAAI	27	45	1
Temperature/Current	Kirk	197		
Temperature/Fire	IAAI	59	40	2
Temperature/Hair Color	Kirk	303		
Temporal Frequency	921	17-4.1.2		
Tennen, Kenneth	IAAI	50	44	1
Terpenes	IAAI	54	44	1
Test Methods	921	9-10.2		
Testimony	921	5-3.3		
Testimony	IAAI	19	41	1
Testimony	IAAI	33	41	3
Testimony	IAAI	22	41	4
Testimony	Kirk	359		
Textiles, Flammability	921	9-10.13		
Texture	921	4-3.2		
Thermal Column	921	1-3		
Thermal Conductivity	921	3-2.1		
Thermal Conductivity	Kirk	23		
Thermal Effect	921	13-4.3		
Thermal Effects, Explosion	921	13-17-5		
Thermal Expansion	921	1-3		
Thermal Expansion	921	4-9		

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Ventilation-Controlled Fire	921	1-3			Wall Displacement	Kirk	119		
Venting	921	1-3			Wall Paper	Kirk	99		
Verbal Information	921	7-3.1			Wallboard	921	4-12		
Victim Injuries	921	4-3.5			Wallboard	921	4-7		
Victim Photographs	921	8-2.5.8			Wallboard	921	4-5		
Victim Position	921	4-3.5			Wallpaper	921	4-3.2		
Video	921	8-2.4			Wallpaper	921	4-5		
Video	Kirk	145			Warrants	Kirk	349		
Vinyl	921	4-5			Waste Basket	921	Table 3-4		
Vinyl Title	921	4-16.1.4			Water Gel Dynamite	Kirk	239		
Visual Information	921	7-3.3			Water in Electrical Box	IAAI	54	43	2
Viton	IAAI	27	42	4	Water Sealers	IAAI	45	41	1
Volatile Materials	921	9-8.2.2			Water Vapor	Kirk	8		
Volt	921	1-3			Waterless Cleaners	921	9-4.2		
Voltage	Kirk	193			Waters, Laurel V.	IAAI	61	41	4
Voltage	Kirk	192			Waters, Laurel V.	IAAI	61	41	3
Voltage Adapters	IAAI	40	41	1	Watt	Kirk	194		
Voltage Drop vs. Friction Lo.	921	14-2.3			Watters, Miles H.	IAAI	53	40	1
Voltage Spike	IAAI	61	44	4	Watts	921	14-2.15		
Voltage Surge	921	14-4.4.1			Wax	921	Table 4-8		
Voltage vs. Arc	IAAI	37	44	2	Wax/Extraction	IAAI	54	44	3
Voltage vs. Pressure	921	14-2.3			Wear on Floor	921	4-18.2		
Voltage vs. Pressure	921	14-2.4			Weather	921	11-3.2		
Voltmeter vs. Pressure Gauge	921	14-2.3			Weather Conditions	921	6-2.3		
Volts vs. PSI	921	14-2.3			Weintraub, Larry	IAAI	11	44	2
Von Waters, Miriam	IAAI	29	44	2	Welding	IAAI	17	44	4
Voyager	IAAI	49	41	1	Welding Arcs	921	14-4.4.3		
Wagner, Mr.	IAAI	62	42	1	Welding of Contacts	921	18-5.3. 2.2		
Wagner, Raymond W.	IAAI	58	41	3	Welding/Copper	IAAI	61	43	1
Wagner, Raymond W.	IAAI	56	44	3	Western Larch	921	Table 3-3.1		
Walker, Joseph	IAAI	49	41	2	Western RV	IAAI	49	41	1
Wall Damage (Inside)	921	4-16.1.3			Whetzel, S. A. Dane	IAAI	42	44	4

Keyword	Book	Section/ Page	Volume	Number	Keyword	Book	Section/ Page	Volume	Number
Zenith Data Systems	IAAI	45	41	1	Zinc	921	4-8.2		
Zicherman, Joseph B.	IAAI	40	40	2	Zinc	921	Table 4-8		
Zicherman, Joseph B.	IAAI	56	41	4	Zinc Chloride	IAAI	9	40	2
Ziegler, David L.	IAAI	38	44	1	Zinc Melting	921	18-5.1.3		

NFPA 921: Its Impact on Fire Investigators and Expert Witnesses in the Courtroom[1]

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The National Fire Protection Association's *Guide for Fire and Explosion Investigations*, known as NFPA 921, is fast becoming one of the most significant authoritative treatises in the field of fire investigations. Its impact on fire and arson litigation is growing at a phenomenal rate in both the criminal and civil courts throughout the United States and in Canada. This paper will introduce how NFPA 921 can be utilized in litigation. It will also provide some practical advice to assist fire investigators and other expert witnesses regarding the use of NFPA 921 so as to improve their effectiveness at trial.

THE GENESIS OF NFPA 921

The last decade has seen fire science and fire protection engineering undergo a period of unprecedented expansion. The rapid growth of the body of knowledge regarding the characteristics of fire and the reconstruction of its cause, origin, and spread, is continually providing new insights into the field of fire investigations. Many seasoned fire investigators, fire scientists, and fire protection engineers will vouch for the fact that many "truisms" that were accepted without question a decade ago are doubtful, or even refuted, today.

These factors are forcing change for fire investigators and other forensic experts. Their work is becoming increasingly knowledge-based. A new emphasis has developed on the accumulation of expertise, not only by way of experience, but through ongoing training and the constant monitoring of trade magazines and scientific journals in the field. A shift towards specialization is evident.

A proliferation of litigation which has come to be known as the "litigation explosion" has also had a noticeable impact on this field. Fire cases are being litigated with increasing frequency in both the United States and Canada. As a result, fire investigators are discovering that their factual findings, as well as their opinions, are being challenged in the courtroom forum.

These changes have generated a need for the development of professional guidelines for investigations. NFPA, the agency recognized worldwide for the standards developed through its technical committees in a myriad of fire protection fields, identified and stepped in to fill this void. A committee representing a multiplicity of disciplines involved in fire investigations was struck. After years of hard work the first edition of NFPA 921 was born in 1992.

SCOPE AND PURPOSE OF NFPA 921

NFPA 921 is best described by its title; it is a *Guide for Fire and Explosion Investigations*. The following excerpt from the introduction to NFPA 921 explains the use intended for the document:

> ...[NFPA 921] was developed by the [NFPA Technical] Committee on Fire Investigations to assist in improving the fire investigation process and the quality of information on fires resulting from the investigative process. The guide is intended for use by both public sector employees who have statutory responsibility for fire investigation and private sector persons conducting investigations for insurance companies or litigation purposes. The goal of the committee is to provide guidance to investigators that is based on accepted scientific principles or scientific research.[2]

The stated purpose of NFPA 921 is "to establish guidelines and a recommended practice for the safe and systematic investigation or analysis of fire and explosion incidents."[3]

The efforts of the NFPA 921 committee are laudable. It has amassed a wealth of information regarding fire investigations and produced a guide containing a vast array of topics that ranged from the interpretation of burn and blast patterns to interview techniques, and from safety equipment for the investigator to laboratory testing. Amendments have since been made. The 1995 edition of NFPA 921 encompasses numerous changes, including new chapters on electrical fires and on the management of major investigations.

In future years, NFPA 921 will be subjected to a regular cycle of review and amendments through the NFPA Standards-Making System, which will help to maintain its currency and its usefulness to fire investigators and those in related fields. The expressed intention of the NFPA 921 Technical Committee is to expand the guide in future editions, to include topics such as the investigation of wildland fires, failure analysis, building and fire protection systems, and the use of accelerant-detection canines.[4]

NFPA 921 serves as a form of textbook to introduce definitions, concepts, and theories and to outline many of the steps involved in the investigation of a wide range of different types of fires. As such, it is beneficial as a general guide for investigators and is useful as an educational tool, but it is not for these commendable purposes that it is receiving so much attention of late. It is its use as a weapon of the adept litigator which has put NFPA 921 into the international spotlight.

While NFPA 921 by definition is a guide and not a standard, it is being applied by some experts and by some attorneys in the courtroom setting as a standard for fire investigations. They imply that the proper analysis of a fire scene requires strict compliance with each and every aspect of NFPA 921. Knowledgeable fire investigators who testify in court regarding their conclusions from a scene investigation run the risk of being accused of professional incompetence and of having their opinions unfairly challenged by those who employ NFPA 921 as an inviolate model for investigations.

THE KEY TO SUCCESS IN FIRE LITIGATION

Cases that turn on the cause of a fire are usually won or lost on the facts, not the law. In other words, if there are gaps or errors in the collection or preservation of evidence, or if the experts called to interpret the evidence are weak, the case is apt to be lost, notwithstanding the most brilliant legal arguments of counsel.

Regardless of whether the case is a criminal proceeding or a civil litigation, there are two keys to success in fire litigation. The first is the strength of the evidence; the strength of the evidence is determined largely by the thoroughness and effectiveness of the investigative team. This comes down to essential matters of detail: the location, collection, and preservation of evidence consisting of a broad range of facts. Everything from witness statements to microscopic samples, and from photographs to weather reports and financial information (if properly collected, documented, and preserved) has a potential place in the success of a fire case.

The second key to winning a fire case is the relative effectiveness of each party's expert witnesses. Central to the triumph of an expert is his[5] ability to properly use authoritative treatises and reference works in presenting his opinion, and to defend against the use of such works in cross-examination at trial.

THE ROLE OF NFPA 921 FOR INVESTIGATORS AND EXPERT WITNESSES

Insofar as NFPA 921 dictates acceptable methods of pinpointing and handling evidence, it serves two possible purposes at the factual level in the development of a fire case. On one hand it is a check, a guideline for investigators, helping them determine what is relevant, where to look, and how to interpret and safeguard evidence. On the other hand it is a balance, a device in the hands of opposing counsel or experts which can be used to test and challenge the merit of an investigation or the validity of the evidence collected.

At the expert level, NFPA 921 is treated as an authoritative treatise. It is fast becoming one of the most recognized authorities in the fire investigations field. The following sections of this paper will review

the foundations of expert opinion evidence and explain the mechanics of the use of authoritative treatises, like NFPA 921, in court.

EXPERT AND NONEXPERT WITNESSES[6]

The general rule is that a witness may testify as to the facts of which he has knowledge, but not as to his opinion. He may give evidence covering his perception of the relevant events, but not the factual inferences to be made. This is so because it is the role of the judge or jury to draw inferences from facts.

Certain exceptions to this rule have unfolded over time. In situations where fact and inference have become intertwined, the law allows a witness to testify as to his opinion. Other exceptions to the rule against opinion evidence include the identification of persons, handwriting, drunkenness, or speed.

One exception to the rule against a witness giving opinion evidence relates to the role of the expert witness. The rationale behind allowing experts to give opinion evidence is that it is sometimes necessary, due to the technical nature of the facts in issue, to have someone furnish the court with scientific or specialized information which is outside of the common knowledge of the judge or jury, but which is necessary to interpret those facts.

Generally speaking, the evidence of an expert will be admissible when the following requirements are met:

- The witness is qualified as an expert in that matter;
- The issue falls within his expertise;
- The evidence given is outside the common stock of knowledge; and
- The opinion is not based upon a question of mixed fact and law.

It is well recognized that when formulating their opinion, experts will have regard to information from several sources. Three general classes of information derive from the expert's personal knowledge or experience:

- Investigations - One source is the results of the expert's investigations in the particular case: his own observations of facts. A fire investigator who has attended at the scene gathers a wealth of information from personal observation.
- Past Experiences - A second source of information is the expert's relevant past experiences. For example, observations made by the expert in prior cases that are relevant to the circumstances in the present case.
- Studies and Experiments - A third source of information is from studies or experiments the expert himself has conducted or in which he has participated, where the circumstances are similar to the case at hand.

Sometimes a witness's opinion may be based upon facts he is asked to assume or facts developed by other persons. Generally speaking, these other facts must be proven in evidence by witnesses with personal knowledge of such facts, or there is a risk that the evidence upon which the expert's opinion is based will be excluded by the operation of the hearsay rule.

Following are some examples of types of information an expert might rely on that do not derive from the experts' personal knowledge or experience:

- Statements - Statements of witnesses or parties in the action are often a key information source for the expert.
- Other Experts' Opinions - Opinions of other experts are also sometimes necessary for an expert to complete his opinion.
- Authoritative Treatises - Research studies, textbooks, and other material written by recognized experts in the field frequently contribute to the foundation of expert opinion.

An expert's opinion is only as good as the facts upon which the opinion is based. Those facts must be proven in evidence or the expert's opinion will have no weight. As a general rule, experts are entitled to take into account a wide range of information in formulating their opinion, but it is incumbent upon the party tendering the expert evidence to establish the factual basis of the opinion through properly admissible evidence.

THE RULE AGAINST THE ADMISSIBILITY OF HEARSAY EVIDENCE

The hearsay rule provides that written or oral statements made by persons who are not parties to an action and are not called as witnesses are inadmissible if such statements are tendered as proof of the truth of the facts contained in the statements or as proof of assertions implicit in such statements. In short, a statement by a witness that "so-and-so told me such-and-such" is generally not admissible. The rationale for the rule is that such statements are suspect as they are not made under oath and no opportunity is afforded the opposite party to cross-examine the maker of the statement.

To what extent will the opinions of experts be admissible when the opinions are based upon hearsay evidence? The first three sources of information listed above as utilized by experts do not offend the hearsay rule. The expert can give personal testimony as to these facts and there would be no objection to the opinion as being inadmissible evidence on the grounds that it was founded on hearsay. This is because an expert's observations, pertinent past experiences, and relevant experiments are facts within the realm of the expert's personal knowledge.

In practice, experts rely upon more than just their own personal observations. It is frequently necessary to call one or more experts who have not had the opportunity to develop information first-hand. Sometimes an expert will base his opinion on facts given in testimony by other witnesses or evidence marked as exhibits at trial. As long as this evidence is accepted as proof of the facts proffered, the factual foundation for the expert's opinion will not offend the hearsay rule.

Sometimes a witness's opinion may be based upon facts he is asked to assume or facts developed by other persons. It is from these sources of information that an objection can be raised that the opinion is founded upon hearsay. The final three sources of an expert's information listed above run the risk of being subject to the hearsay rule. A large body of evidentiary rules, statutes, and cases govern the circumstances in which out-of-court statements and the opinions of other experts are admissible. Our focus is on the last category of information: the use of authoritative treatises in expert opinion evidence or in the cross-examination of an expert witness. It is these rules that underlie the importance of NFPA 921 in a litigation setting.

EFFECT OF AUTHORITATIVE TREATISES ON EXPERT EVIDENCE

Research studies, textbooks, and other written material of recognized experts in the field frequently contribute to the foundation of expert opinion. Such works are commonly referred to as learned or authoritative treatises.

As an example of the use of authoritative treatises in the formulation of an expert's opinion, consider how an expert will interpret the condition and location of glass shards found at a fire scene. In addition to considering his own previous experiences with glass, the expert will probably analyze the fragmented glass in light of information about the properties of glass found in a recognized reference work.[7] The edges of the broken glass will display fracture lines if the glass is broken mechanically — for example, by impact — different from those evident if it was broken from thermal stress as might happen in the uneven heat of a fire. The authoritative treatises point to crazed glass as an indicator of a very rapid heat build-up during the course of the fire. In the end result, the information from the authoritative treatises are combined with the expert's own store of knowledge to help him formulate his opinion regarding the effect of the condition of the glass from the fire scene.

In both Canada and the United States, certain rules govern the extent to which authoritative treatises can be used as an exception to the hearsay rule. Below is a general statement of the rules for each country.

USE OF AUTHORITATIVE TREATISES IN CANADA

In Canada, the use of learned treatises in civil or criminal litigation was described by the Ontario Court of Appeal in *R.* v. *Zundel*:

> [A]n expert witness may give evidence based on material of a general nature which is widely used and acknowledged as reliable by experts in that field. This exception, however, has hitherto been confined to a few narrow classes of cases such as, for example, mortality tables and a standard pharmaceutical guide: see Pattenden, "Expert Opinion Evidence Based on Hearsay", [1982] Crim. L. Rev. 85 at pp. 90-19; *Cross on Evidence*, 6th ed. (1985), at p. 452[8]

The Ontario Court of Appeal went on to quote Professor Pattenden's article as describing a related and overlapping exception to the hearsay rule:

> [T]o some extent all opinion evidence by an expert contains hearsay. Very few experts acquire their specialist skill entirely through first-hand experience. Provided the hearsay on which the expert relies is of a sufficiently general nature to be regarded as part of the corpus of knowledge with which an expert in his field can be expected to be acquainted, no objection will be taken to his evidence on this ground. Referring to the evidence of an expert valuer Megarry J. said in *English Exporters Pty. Ltd. v. Eldonwall* ([1973] 1 Ch. 415 at 420):
>
> > "As an expert witness, the valuer is entitled to express his opinion about matters within his field of competence. In building up his opinions about values, he will no doubt have learned much from transactions in which he has himself been engaged, and of which he could give first-hand evidence. But he will also have learned much from many other sources, including much of which he could give no first-hand evidence. Textbooks, journals, reports of auctions and other dealings, and information obtained from his professional brethren and others, some related to particular transactions and some general and indefinite, will all have contributed their share ... [T]he opinion ... is none the worse because it is in part derived from the matters of which he could give no direct evidence ..."
>
> This exception to the hearsay rule (for such it surely is) is largely based on necessity, but a **recognition of the greater ability of the expert than the court to evaluate the reliability of background hearsay may also be a factor**.[9] [Emphasis added by the Court]

On the basis of this latter exception to the hearsay rule, the expert witness will be entitled to rely upon his reference book authorities, without the necessity of having the authors of these works called to testify.

Through what mechanics are authoritative treatises actually employed by the expert at a trial in Canada? Guidance is provided by the Alberta Supreme Court, Appellate Division case of *R. v. Anderson*.[10] The following excerpt describes how the authoritative material can be used in direct examination:

> When a medical man or other person professing some science is called as an expert witness, it is his opinion and his opinion only that can be properly put before the jury. Just as in the case of a witness called to prove a fact, it is proper in direct examination to ask him not merely to state the fact, but also how he came by the knowledge of the fact, so in the case of an expert witness called to give an opinion, he may in direct examination be asked how he came by his opinion. An expert medical witness may therefore upon giving his opinion state in direct examination that he bases his opinion partly upon his own experience and partly upon the opinions of text writers who are recognized by the medical profession at large as of authority. I think he may name the text writers. I think he may add that his opinion and that of the text writers named accords. Further, I see no good reason why such an expert witness should not be permitted while in the box to refer to such textbook as he chooses, in order, by the aid which it will give him, in addition to his other means of forming an opinion, to enable him to express an opinion. And again the witness having expressly adopt at his own the opinion of a text writer, may himself read the text as expressing his own opinion.

And in cross-examination:

> On cross-examination the judge should be careful to see that an improper use is not made of textbooks, practically to give in evidence opinions of absent authors at variance with those of the witness. It is quite apparent that if the witness is asked about a textbook and he expresses ignorance of it, or denies its authority, no further use of it can be made by reading extracts from it, for that would be in effect making it evidence, but if he admits its authority, he then in a sense confirms it by his own testimony, and then may be quite properly asked for explanation of any apparent differences between its opinion and that stated by him.[11]

USE OF AUTHORITATIVE TREATISES IN THE UNITED STATES

As in Canada, authoritative treatises are generally not admissible for the truth of their contents. This is so for two reasons: first, because such use would offend the hearsay rule; and second, because the admission of technical or scientific publications might tend to confuse or mislead the jury. There are, however, exceptions to this general rule. While the rules regarding the use of authoritative treatises vary among jurisdictions,[12] the following points provide a general summary:

- Books of exact science containing undisputed facts which have withstood the test of time can be used in evidence. Examples of such reference works are dictionaries and tables of weights and measures. While NFPA 921 is not such a publication, to the extent that portions of NFPA 921 contain accepted definitions or unchallenged statements of scientific fact, such portions may be admissible into evidence as to the truth of their contents.

- Most jurisdictions permit the use of authoritative treatises in cross-examining expert witnesses at trial where the witness has specifically relied on a treatise in support of his opinion as rendered on direct examination.

- Where an expert has not relied on a given authority in formulating his opinion as presented in direct examination, there are three main lines of authority regarding the extent to which an expert can be cross-examined on an authoritative treatise:

    1) An expert who relies on authorities to corroborate his opinion can be cross-examined on other authoritative treatises which are not necessarily the same as those he relied upon.

    2) An expert may be cross-examined on an authoritative treatise, whether he has relied on authorities in forming his opinion, where the authoritative status of the work is established by the admission of the expert, by another expert, or by judicial notice.

    3) A cross-examiner may use authoritative treatises to cross-examine a witness on his qualifications (as distinct from the cross-examination of the expert on the substance of that expert's opinion). The authoritative standing of the treatise must, however, be established in evidence.

The Uniform Rules of Evidence and Federal Rules of Evidence address the use of learned treatises under Rule 803(18), which creates the following exception to the hearsay rule:

> The following are not excluded by the hearsay rule, even through the declarant is available as a witness: (18) Learned treatises - To the extent called to the attention of an expert witness upon cross-examination or relied upon by him in direct-examination statements contained in published treatises, periodicals, or pamphlets on a subject of history, medicine, or other science or art, established as a reliable authority by the testimony or admission of the witness or by other expert testimony or by judicial notice. If admitted, the statements may be read into evidence, but may not be received as exhibits.

In direct examination, an authoritative treatise cannot generally be read into evidence or marked as an exhibit at trial, even if the expert is relying on the work in formulating his opinion. It is equally inappropriate in most cases for experts to recite passages of a reference work from memory. Experts can, however, refer to treatises that corroborate their opinions.

In cross-examination, where the expert does not rely on the treatise to corroborate his opinion in direct examination, and where the expert does not admit that the authoritative nature of the treatise in issue, the use of the treatise will turn on the ability of opposing counsel to prove that the treatise he wants to use in cross-examination is authoritative. The following factors are relevant to establishing the authoritative nature of particular reference material:

- The status of the writer or writers of the work within the profession.

- The general recognition or acceptance of the work in the profession as authoritative, not just the reputation of the publisher or the journal in which the work was published.

- Evidence by another expert in the field who testifies as to the authoritative nature of the work.

- The use of the treatise as a standard text in teaching the subject at issue within the profession.

The circumstances in which NFPA 921 was created and its growing popularity within the field of fire investigations qualify it to be accepted as an authoritative treatise in most fire cases, as demonstrated when it is measured by the above criteria:

- The document was written by a committee, the membership of which was chosen in a competitive system, based upon their individual qualifications. Many of the committee members are, in themselves, authors of authoritative works in the field. The committee represents every major sector of the fire investigation community and holds representation from the leading fire investigation organizations.

- NFPA 921's popularity is growing to make it one of the best known and most widely accepted guides in the domain of fire investigations. The NFPA's Standards-Making System, which was the process through which the document was generated and will continue to be developed, lends credence to the authoritative weight of the document.

- Frequently, even if an expert does not admit the authoritative status of NFPA 921, the opposing expert will have relied on that document during his investigation or in the formulation of his opinion and will testify as to its authoritative nature.

- NFPA 921 has been adopted as a central teaching aid by both public and private organizations leading the way in fire investigation education and certification programs.

As a result of these factors, every fire investigator or other expert whose disciplines are affected by NFPA 921 can expect to face that document on the witness stand. It is no longer a force that can be ignored in any fire investigation where litigation is a possible consequence.

PRACTICAL ADVICE FOR THE FIRE INVESTIGATOR AND OTHER EXPERTS

Examination and cross-examination on an expert's use of authoritative literature is a critical part of forceful advocacy through expert testimony. The following points contain some practical advice regarding the use of authoritative treatises, especially NFPA 921, for fire investigators and other experts who become involved in fire litigation:

- Purchase your own copy of NFPA 921 and new editions as they are issued.

- Having obtained NFPA 921, read it thoroughly; and then read it again, and again, and yet again. Also read the parts that do not apply to you, as you may be called upon to explain what does not apply and why not.

- Dog-ear it, underline it, color-code it, tab it. Do whatever you must do to develop a working knowledge of what NFPA 921 contains so that you can, if called upon to do so, justify the way in which you use NFPA 921 or why you did not use parts of it in a particular case.

- If counting on one work of an author as reliable, ensure that the author has not a more recent work in which his opinion changes. Likewise with NFPA 921, keep current on changes. Become appraised of new editions, technical interim amendments, formal interpretations, and proposals for change relating to any portion of the document that affects your area of expertise or your investigative responsibilities.

- Since NFPA 921 is likely to have an impact on you and your profession, take the trouble to have input into the course of its development. Help to make it accurate and authoritative. Participate in the continued evolution of the document, if not as a NFPA Technical Committee member, then through the public input opportunities inherent in NFPA's Standards-Making System.

- If you do not agree with the merit or accuracy of some portion of NFPA 921 which relates to your job, do something about it. For example, propose a change through the NFPA Standards-Making System, or write an article

in a fire journal explaining and documenting your point. If you are later called to task on that issue, you may be in a better position to substantiate your position in court.

- Be prepared to justify your decisions and actions in the course of any particular fire case in light of the principles of NFPA 921.

- Never profess reliance on NFPA 921 or any other reference work as authoritative for the proposition in issue without carefully checking both the textbook and any references contained within it on the point.

- Never accept NFPA 921 or any other reference work presented to you in cross-examination as authoritative on the point in issue without having read it carefully with specific reference to that point. If opposing counsel asks if the book is a recognized authority on the issue and you recognize either the author or the book as an authority in the field, you may be well-advised to request an opportunity during an adjournment to carefully read the proffered sections of the text, as well as any related portions of the same text.

- Educate the lawyer who will be calling your evidence about NFPA 921 and its status in the fire investigation community. The lawyer will then be in a better position to assist you to become familiar with how authoritative treatises like NFPA 921 can be used in the particular jurisdiction and how best to address the document, both in your examination and in cross-examination.

- When reviewing a publication and deciding whether to accept it as authoritative, ensure it is the most current edition of the work and examine any footnotes or other references. Look carefully at the context in which the author discusses the issue and note any features that distinguish it from the case at hand. If qualifications are necessary before recognizing an authority, make them known to the cross-examiner. For example, "This author is someone I recognize as authoritative on general principles of fire investigation, but I do not accept his work as current in the field of concrete spalling."

- Always assume that the opposing lawyer who offers a text as an authority has studied that text as he would for a critical law school examination. Do not underestimate the opposing lawyer's ability to master technical, complicated, or scientific material.

- If there is some material contained in the authorities on the issue that might be raised by opposing counsel in cross-examination, prepare the lawyer who will be calling your evidence. This may help him to prepare for an adequate re-examination to correct any wrong impression that may be left during cross-examination.

- Do not accept a quote from a book accepted as an authority without asking to see the book in order to put the quote in context.

The "battle of the experts" is nowhere better fought that in a trial where the issues are technical and extensive use is made of authoritative literature. The best advice for the effective use of textbooks and other references is that in preparing the case, both counsel and the expert ought to study the authoritative works on the subject in issue with unequaled zeal. Knowing that NFPA 921 has assumed a prominent position as an authority in fire investigations, it ought to be accorded appropriate attention. This will be the best armor for any fire investigator or other expert under fire during cross-examination on the literature on topic, as well as the best weaponry for your lawyer who will have his turn when cross-examining the opposing expert.

CONCLUSION

In closing, remember that everyday is exam day. If you testify at trial or in any other court proceeding in a fire case, you might well be asked about NFPA 921. Not only might you be asked about what you do or do not accept as authoritative on the day you are asked, but also about what you knew of NFPA 921 and what you did or did not apply from that guide in conducting a particular investigation, days, months, or years ago. Not only will the outcome of your case depend on your answers, in some situations, so might the security of your job.

This paper will be have served its purpose if it has demonstrated the importance of NFPA 921 in the litigation context and if the readers come away with a better working knowledge of how to conduct their investigations and otherwise prepare for the day they are faced with NFPA 921 on the witness stand.

ENDNOTES

[1] The statements of law contained in this article are generally applicable in both the United States and Canada, though there may be variations among jurisdictions and in the way in which the law is applied to given fact situations. This material does not intend to offer legal advice in specific situations. The services of a competent lawyer in the appropriate jurisdiction should be sought in individual cases.

[2] National Fire Protection Association (1995). *NFPA 921, Guide for Fire and Explosion Investigations*, National Fire Protection Association, Quincy, MA, p. 1.

[3] *ibid.*, p. 5, para. 1-2.

[4] *ibid.*, p. 1.

[5] Wherever the masculine is used in this paper it includes the feminine. It is intended to accord equality to both men and women, without having to engage in verbal acrobatics such as "him or her; he or she."

[6] Derived, in part, from Hewitt, T. D. (1994). *Fire Loss Litigation in Canada: A Practical Guide*. Carswell, Thomson Professional Publishing, Toronto, Canada, pp. 10-13 to 10-14, 11-10 to 11-15, and 11-23 to 11-27.

[7] The following evidential indicators of glass can be found in two authoritative works: National Fire Protection Association (1995). *NFPA 921, Guide for Fire and Explosion Investigations*, National Fire Protection Association, Quincy, MA, para. 4-8, 4-10, 4-13, 27-5, 13-3, 13-13; and DeHaan, J. D. (1991). *Kirk's Fire Investigation*, 3d ed. Brady, A Prentice Hall Division, Englewood Cliffs, New Jersey, pp. 126-130.

[8] (1987) 31 C.C.C. (3d) 97 at 146.

[9] *Supra*, at 146-147, quoting Pattenden, *Expert Opinion Evidence Based on Hearsay*, (1982) Crim. L. Rev. 85 at 93, footnotes omitted by the court.

[10] (1914) 5 W.W.R. 1052 at 1067, per Stuart, J.

[11] *Supra* at 1053 per Harvey, C. J.

[12] The rules in a particular jurisdiction will depend on the development of the common law and the rules of evidence, or in some cases, on statutes that have been enacted regarding the admissibility of authoritative treatises. Legal advice should be sought regarding the applicable rules in particular cases.

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Using the Electrical System to Help Reconstruct the Fire Scene

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A popular fall-back position for arson defense attorneys is to blame the fire cause on ignition of combustibles by an electric arc. The brilliant white light of the arc with its pyrotechnic aura and nominal 2800°C (5000°F) temperature makes it a popular visual effect for movies and television. Movies and television are not real life and the arcs generated for visual effects are not the arcs of our everyday electrical systems. Below 375 volts, the arc created by shorting electrical wires together lasts only 8 milliseconds (.008 second) and has a limited amount of heat that makes it a poor ignitor of combustibles. Therefore, arcs created in the 120/240 volt electrical system found in residences and commercial buildings are also poor sources of ignition. These arcs can ignite some gases and finely divided materials such as dryer lint, but they have little effect on solids. Otherwise, manufacturers would be producing arc ignitors for our wood fireplaces instead of what we commonly find – arc ignitors for gas stoves and matches for wood fireplaces.

The beads that are the residue of the arc provide mute testimony that an electrical incident occurred before or during the fire. Many investigators, upon finding such beading, will offer it as proof of an electrical cause without realizing that most arcs are due to the fire burning insulation off of the wiring so that the conductors short together. However, these beads can provide important information about the location of the origin and the sequence of the fire's spread. Relating the position of the beads that are formed due to electrical "faults" to the layout of the electrical system will help establish the area where the fire and the energized system first coincided.

Unless a disinterested witness observes and documents the start of a fire, the point of origin and cause is often determined by circumstantial evidence and the elimination of other sources. In part, the investigator relies on education and experience to reconstruct the scene by using physical evidence that survived the fire. This evidence consists of unburned combustibles and noncombustible materials such as brick, tile, steel beams, plumbing, and electrical pipes and electrical wiring. This and the unburned sections of the floors, walls, ceilings, and furnishings are used by the fire investigator to delineate fire patterns and help draw a picture of the fire origin and progression.

The fire investigator is doing much the same as an archaeologist or paleontologist when looking for artifacts that have survived intact long enough to provide a window back in time. Unfortunately, time and the effects of the fire can modify some artifacts, such as smoke and burn patterns, to the point that it becomes difficult to determine at what time the pattern was created during the fire's progression. Fortunately, the electrical system can provide a more certain window into the past because its remains are less fragile than that of combustibles.

Concurrent with the origin and cause examination, the electrical system should be examined to aid in the determination of the point of origin. The electrical system's copper wire, with its points of beading, often survives the temperatures of the fire. Some of the points of electrical faulting may be changed by the melting and chemical effects of the fire, but this can be taken into account during the examination.

The copper wiring used in residential and commercial buildings and appliances will melt at a nominal temperature of 1082°C (1981°F). This temperature, higher than that often encountered for significant periods of time in the normal fire environment, can easily be achieved locally by arcing.

The arcing is due to electrical current flow between conductors or conductors and ground, called an "arcing fault."

True beading (Figure 1) of the copper conductors due to the electrical arc consists of the spherical beads, notches, lines of demarcation, splattering, and other indications of the high-energy, chaotic activity associated with electrical arc. These beads are like snowflakes, no two are exactly alike, but similarities abound. Investigators, scientists, and engineers have created beads in the laboratory in an attempt to categorize the characteristics. These beads and other types of damage to copper wiring have also been reproduced in structural test fires. However, a metallurgist with experience in arcing damage to copper may have to be consulted for more ambiguous cases.

Figure 2 shows fire attacking an appliance cord's insulation. The source of current (plug) is at the left end of the wire. When fire #1 burns through the insulation, an arcing fault will occur if the wires touch each other or the carbon residue conducts enough electricity. This will cause the wires to bead. If the fire is slowly developing, this faulting will be localized around fire #1 because the over current protection device (fuse, circuit breaker) has time to open. Since the local energy in the arc is sufficient to vaporize copper, the telltale beads form from the cooling copper as the arc extinguishes during the alternating cycle of current (120 times per second). The formation of the beads results in welding the conductors together, severing the conductors, and/or blowing the fuse or circuit breaker protecting the wiring. This means that a subsequent fire attack at point #2 on the wire downstream from the original point of arcing produces no further arcing since the electrical supply had been cut off at this point. Subsequent fire attacks from fire #3 on the wiring upstream of the first fault point may result in arcing if the circuit has not been de-energized. Therefore, a single wire can indicate where it was first damaged by the fire, by finding the point of faulting farthest from the source. An energized extension cord feeding a heater in a room will have the tendency to fault close to the heater if the heater was at the origin of the fire. If the fire started in the wall receptacle, we would not expect to find faulting inside the heater or in the line cord since the faulting in the receptacle would de-energize the receptacle and remove the source of current at the plug.

An effective way of providing a nontechnical jury with a visual representation of this method is to use the water hose analogy. This is an extension of the water flow analogy of electricity which has been proven effective in describing voltage by water pressure, amperage by water flow-rate, and resistance by friction. The water hose extension of this analogy centers on the use of the puddle pattern of a garden hose to demonstrate how the point of puddling farthest from the source is the most likely point where the hose was first cut. In Figure 3 water will flow from cut #1, leaving a puddle residue. Subsequent cuts downstream at point #2 will not leave puddles since the water source has been interrupted at cut #1. Subsequent cuts upstream will leave puddles until the faucet (circuit breaker) is turned off. If the hose and puddles are examined after being cut, the puddle farthest from the source is the point of first damage. The puddle in this case is analogous to the arc bead.

Back in the electrical world—appliances that start fires due to internal failure tend to show signs of electrical faulting in or close to the appliance. Placing the appliance and cord back at the scene will help the investigator to determine if the cord was stretched out, coiled up, or shielded in some manner from the effects of the fire. This is useful in understanding the effects of the flame impingement on the arc patterns. Placing flags or markers at the points of faulting and transferring these locations onto the scene diagram will provide spatial clues to the origin of the fire.

A typical room (Figure 4a) will have furniture and other objects that can partially shield the wiring. The effects of these objects has to be taken into account. In live burn tests it has been confirmed that a fire starting in the television set at the right side of the room (Figures 4a, 4b) results in arcing in the television and around the television and the lamp. If the fire starts in the center of the room (Figure 4c) or in the easy chair (Figures 4d, 4e) the fault points in the electrical cords can help to locate the origin. Faulting in these cords helps eliminate a fire origin in the wiring inside the walls.

Multiple wires can be used to help locate an origin in two-dimensional space by providing fault points on a diagram of the electrical system as in Figure 5. Here a single, radially expanding fire, burns through the insulation of branch circuit wires fed from the single source of the electrical panel. The lines drawn through the points of faulting farthest from the source converge at the origin. This method is most effective in factories when the branch circuits are surface mounted at ceiling level.

The layout of the electrical system in a factory or commercial building readily lends itself to an investigation of the arcing patterns in the branch circuits and feeders. These conductors are often continuously energized, have high available fault

current for larger beads, and are physically heavy enough to resist gross melting from the heat of the fire. In Figures 6a through 6c the fire impinges upon the energized wiring, leaving signs of beading as it progresses into the main electrical panel. The arcing in the branch circuit wiring indicates that the fire did not start in the service panel, since an early fire in the panel (Figure 7) would trip the circuit breakers, de-energizing the branch circuits before they could arc.

Sometimes the building wiring is not radially spread out from a source, but is looped around the periphery such as in the workshop of Figure 8. Documenting the points of faulting on a sketch of the workshop shows that the arcing occurred in a straight run of nonmetallic cable ("Romex") behind the wood stove. The faulting occurred in an area where mechanical damage was unlikely. A subsequent interview with the homeowner revealed that the stove had been stoked with scraps shortly before the fire. The fire investigator's analysis of the fire patterns also confirmed an early fire in this area.

The third dimension of the origin can be determined by examining vertical runs of wiring. For example, a receptacle fed from a branch circuit as shown in Figure 9 feeds a line cord that has signs of electrical beading. This indicates that the early fire was in the room and not in the wall because an internal wall fire would de-energize the receptacle so no faulting could occur in the line cord. However, faulting above the ceiling only, points to an attic origin. Faulting in both the line cord and the attic is indicative of a room fire first attacking the line cord and then progressing into the attic before the branch circuit fuse or breaker had time to open. This could indicate, in part, a well-developed fire attacking the wiring, too large a protective fuse or circuit breaker, too much impedance in the circuit, or multiple origins. Plotting these points on a three-dimensional diagram that includes the layout of the pertinent sections of the electrical wiring can provide information for the cause and origin investigator to use in the examination of potential fire causes.

This method of using the damage to the electrical system has been based on multiple tests on electrical wiring and components in both laboratory and structural burn situations. The main things to be wary of are the effects of wiring placement in relation to objects in the fire scene and the nonelectrical damage caused by the fire and other activities. Factors to be considered regarding the placement of the wiring are: whether the wires are exposed or buried in the walls and ceiling, what materials may have shielded the wiring system, the thickness of the wire's electrical insulation, the size of over current protective devices, and the number of sources of electrical energy. An electrician with experience in wiring can be of great help in considering these factors.

The effects of the fire itself can cause misleading damage by causing gross melting or chemical reactions that can cover up or mimic arc marks, rendering them suspect or useless. The investigators can also damage the wiring during their examinations. These damage patterns contrast with that shown by arcing faults. Figure 10 shows the gross melting of the conductors due to the heat of the fire. This melting is a less chaotic activity than arcing and there is more sagging and thinning of the conductors. There are a few sharp lines of demarcation as the melted copper flows, however, some spherical beads may form from gas pockets.

Figure 11 shows the effects that aluminum and zinc have on copper in the fire environment. The silver and brass colors of the aluminum or zinc-contaminated wires should alert the investigator to the possibility that the damage on the wiring is from the reduced melting temperature of the alloys and not that of arcing. These alloys may damage the wiring by themselves or may be covering up an arc, thereby rendering it of little value for pattern analysis.

Mechanical damage to the wiring (Figure 12) may take the form of fracturing of embrittled wiring as the scene is disturbed, stretching of the wiring as the structure falls, or cutting by the investigators.

The lower melting temperature of aluminum wiring limits its use in this method since it will have extensive gross melting in all but the smallest of fires. However, if gross melting is limited, this arc pattern method of analysis may be useful.

Courtroom battles have centered on whether an alleged point of faulting is really due to the effects of the fire. Again, experienced metallurgists may be called in to provide opinions on the source of a bead. Also, experience in creating beads, thermal melts, and alloys should be pursued.

The origin(s) determined by examination of the electrical system should correlate with the origin(s) determined by the other standard investigative methods. It is important that the electrical investigator and the origin-and-cause investigator reach a consensus as to point(s) of origin before the cause can be determined. The possibility of an electrical cause should then be investigated as part of the continuing examination.

Two examples are given: the first (shown in Figure 13) is that of a room containing an old, wall-mounted, supposedly turned "OFF" electric heater, behind a rack of clothing. A fire occurred at night which was blamed on a propane heater mounted above the room. Analysis of the electrical system revealed that the main building service wires and the branch circuit that fed the electric heater both ran past the propane heater and through boxes of combustibles. The shadow patterns on the electric heater switch indicated that it was in the "ON" position, and beading due to electrical faulting was also found on the wiring inside. After a lengthy trial, the jury agreed that the electric heater started the fire in the clothing after it was inadvertently energized.

The second example (Figure 14), shows the diagram of a residential basement in which multiple points of faulting were noted in the "Romex" strung through the joists. The fault points could not be connected by a rational pattern of fire progression and no single fault point would account for the others. Upstairs faulting was noted that also was not connected to the basement pattern. The owner, upon being confronted with the above information, confessed to first degree arson. He admitted that he used a propane torch to cause faulting in the wiring, since he had heard that the fire would be called "electrical" if beads were found. He did not think about any significance to his pattern of faulting.

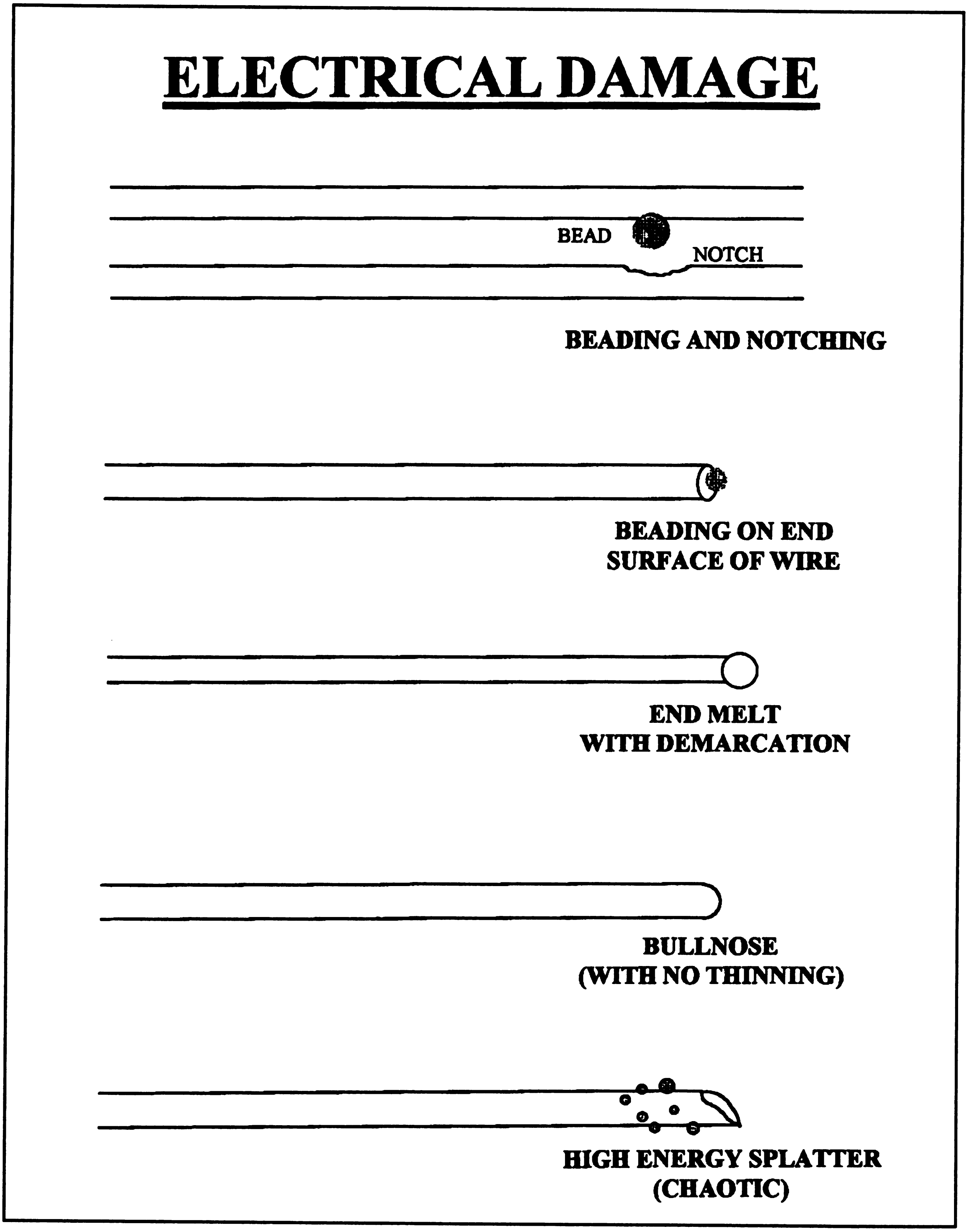

Figure 1. Examples of some of the characteristics of electrical arcing residue on copper wire.

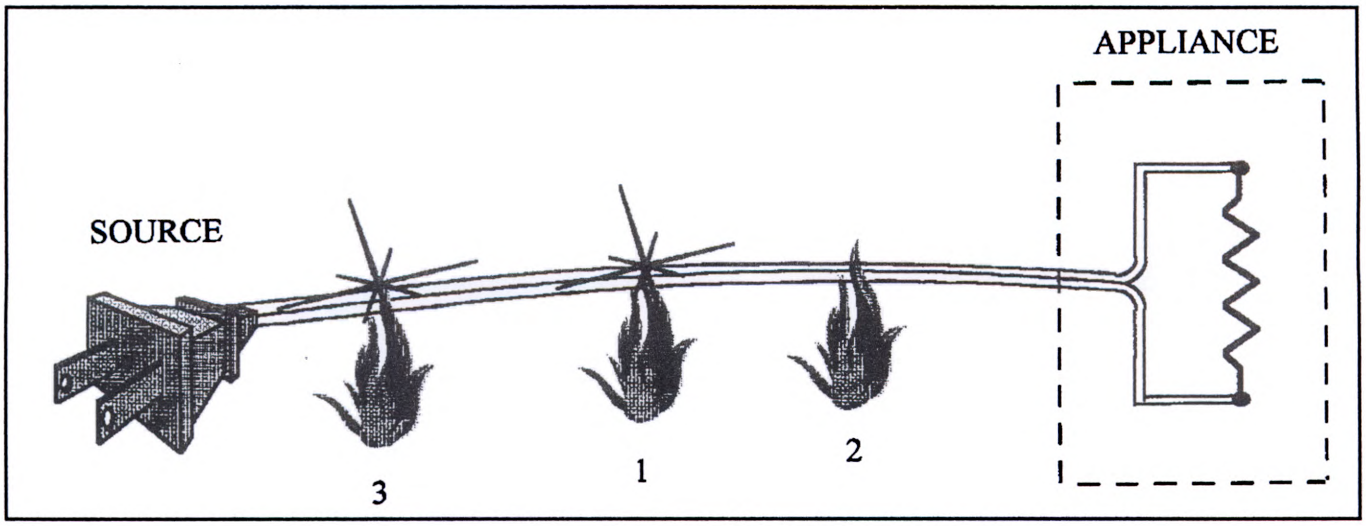

Figure 2. Fire attacking a line cord - farthest point of faulting from the source is the origin.

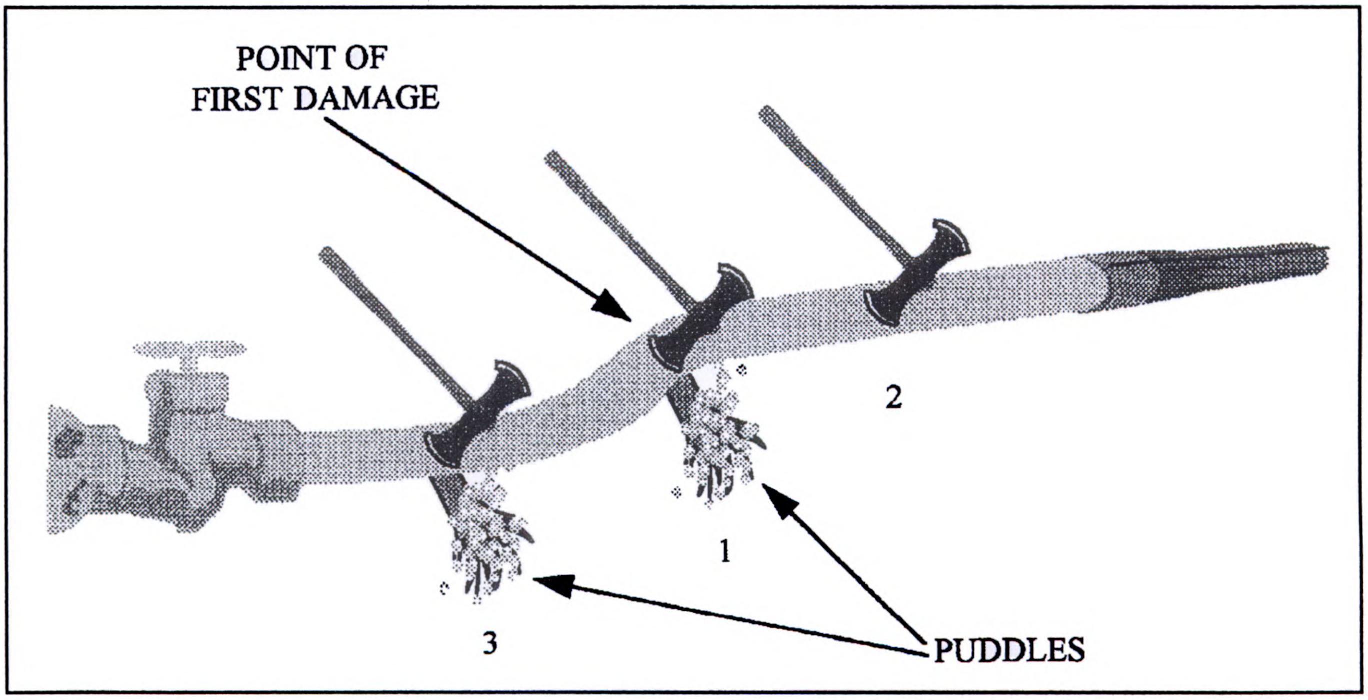

Figure 3. The water hose analogy for Figure 2.

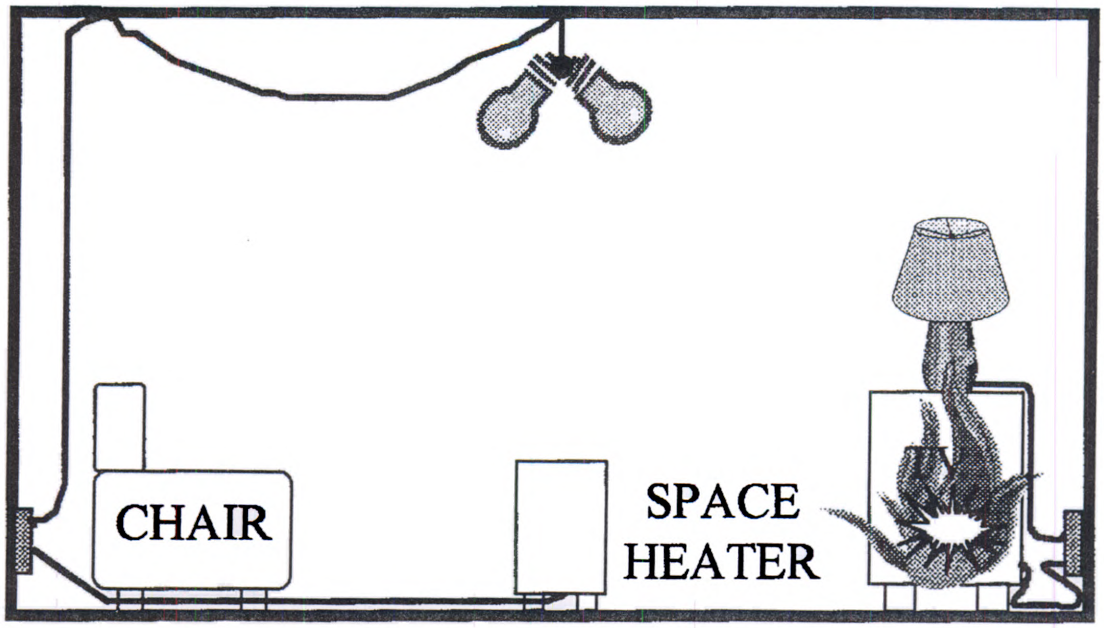

Figure 4a. Fire inside television results in internal arc.

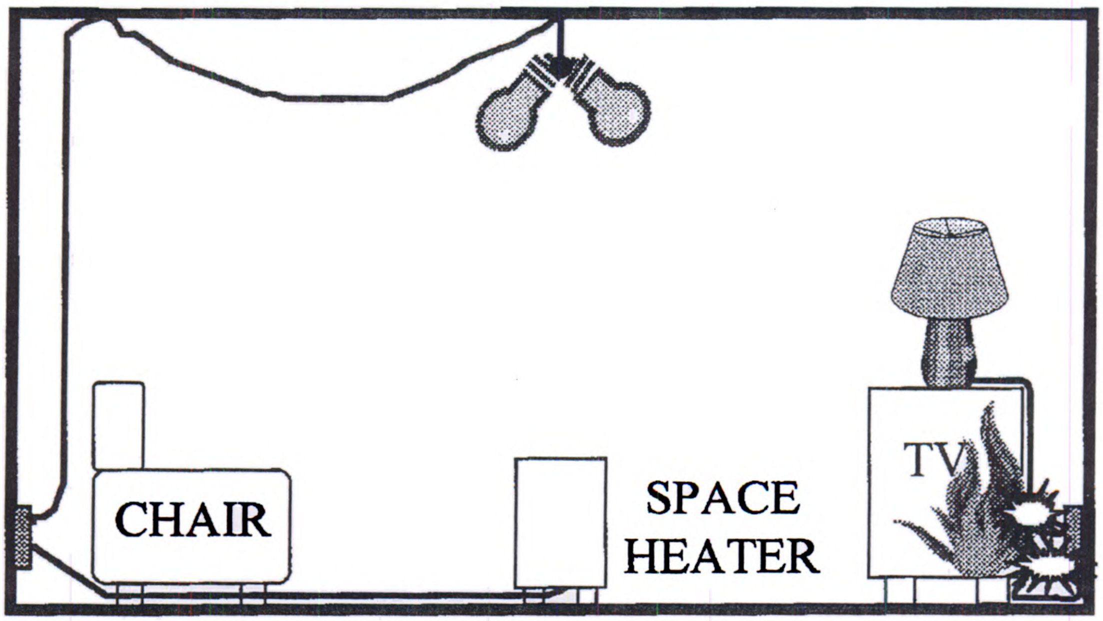

Figure 4b. Television fire may cause external faulting in line cord if circuit is still energized.

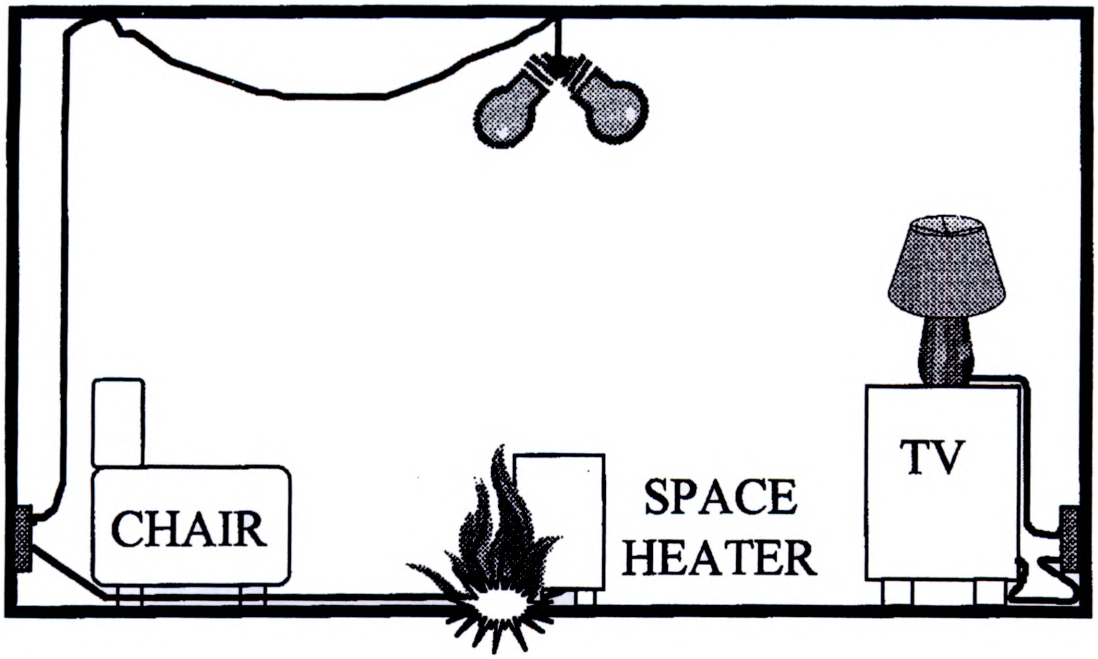

Figure 4c. Space heater causes electrical damage close to itself.

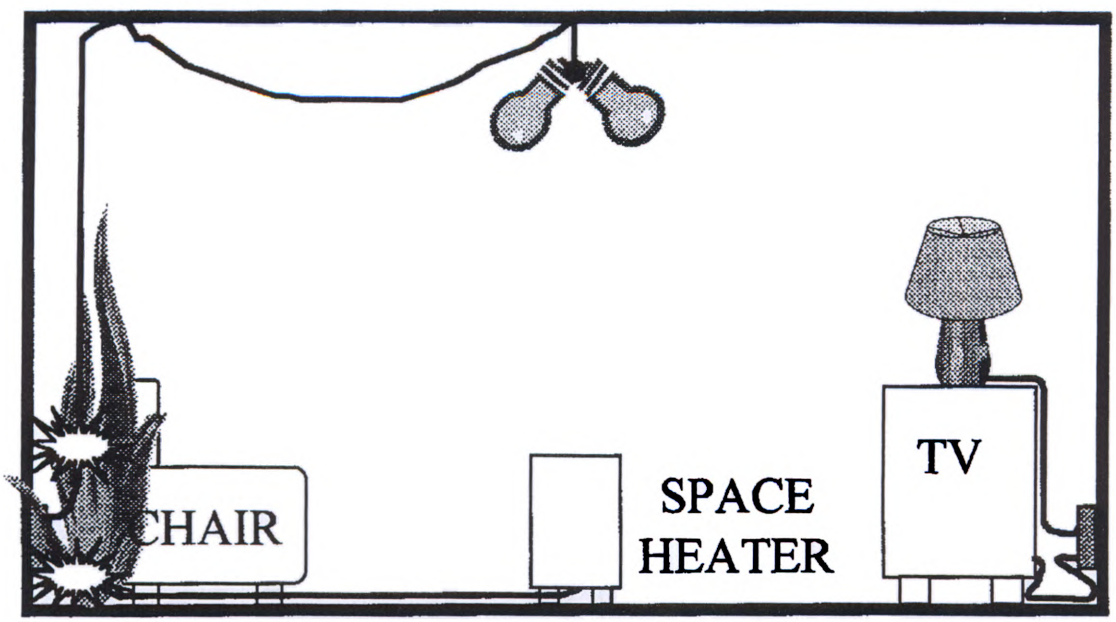

Figure 4d. Low chair fire will fault nearby energized line cords.

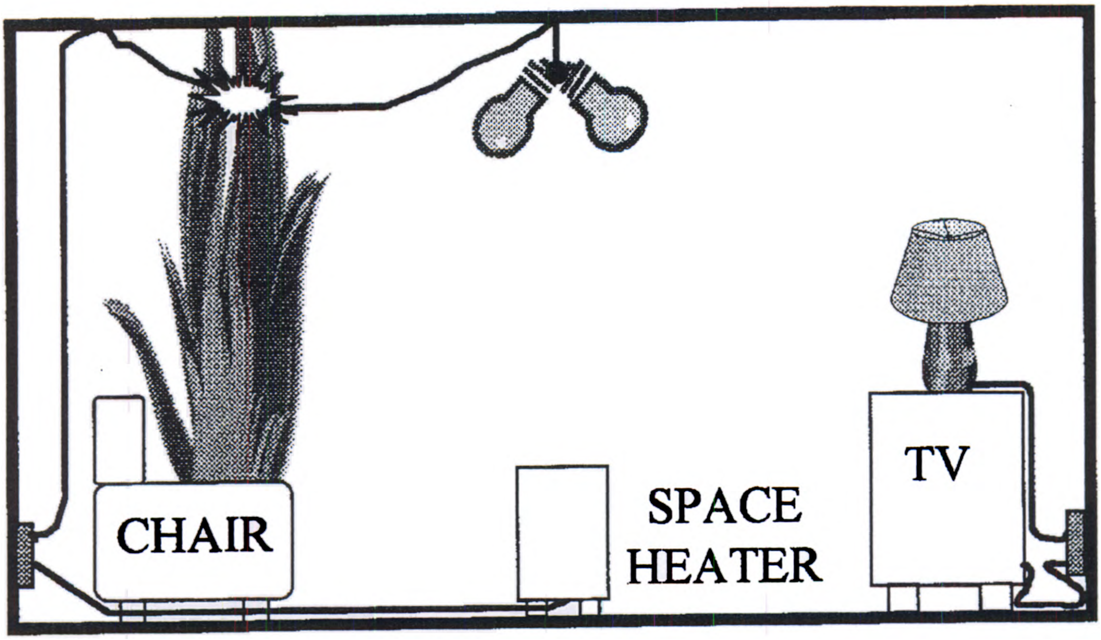

Figure 4e. Fire on top of chair may damage overhead cord. Base of chair will protect heater

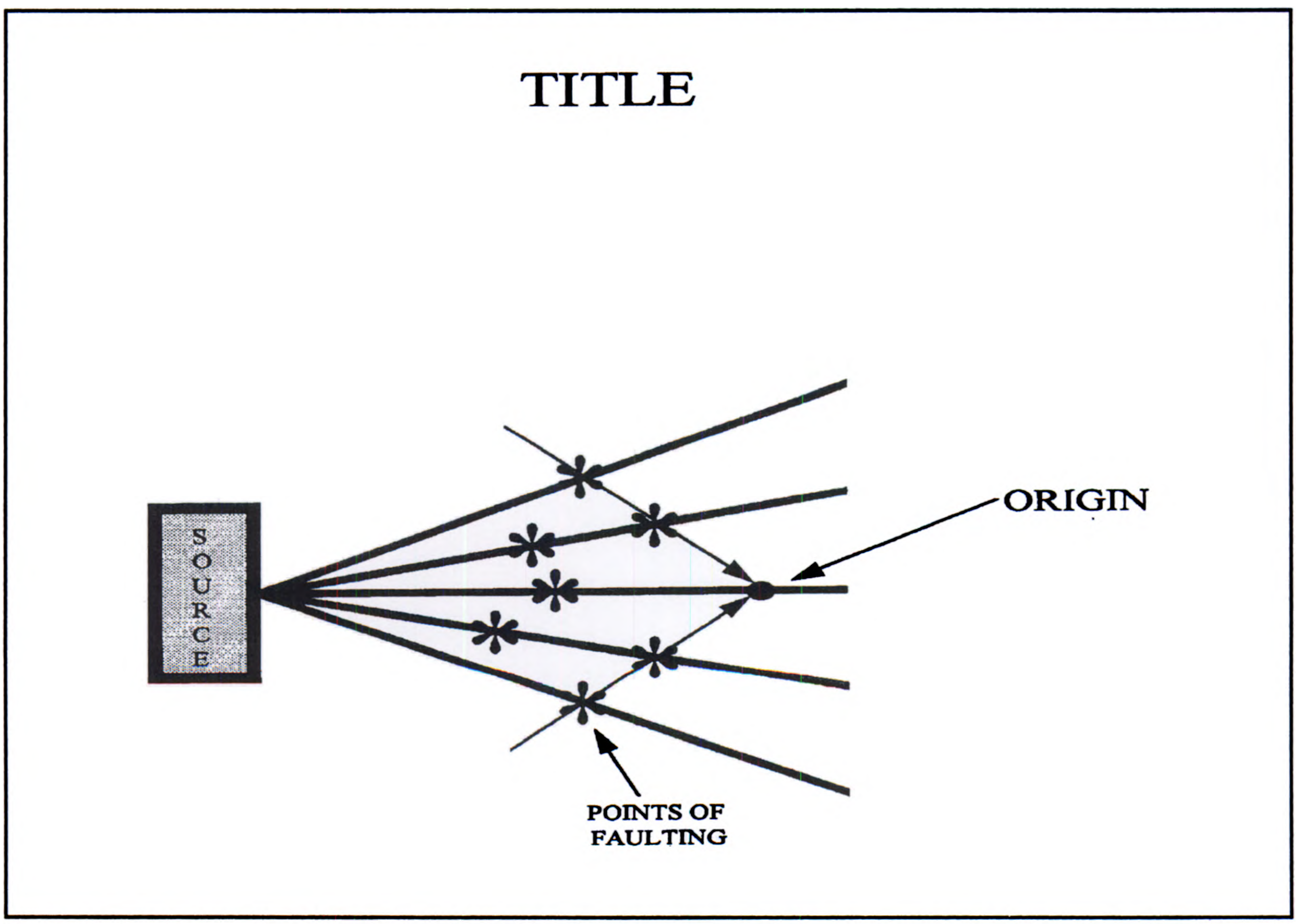

Figure 5. Lines through farthest points of faulting coincide at origin.

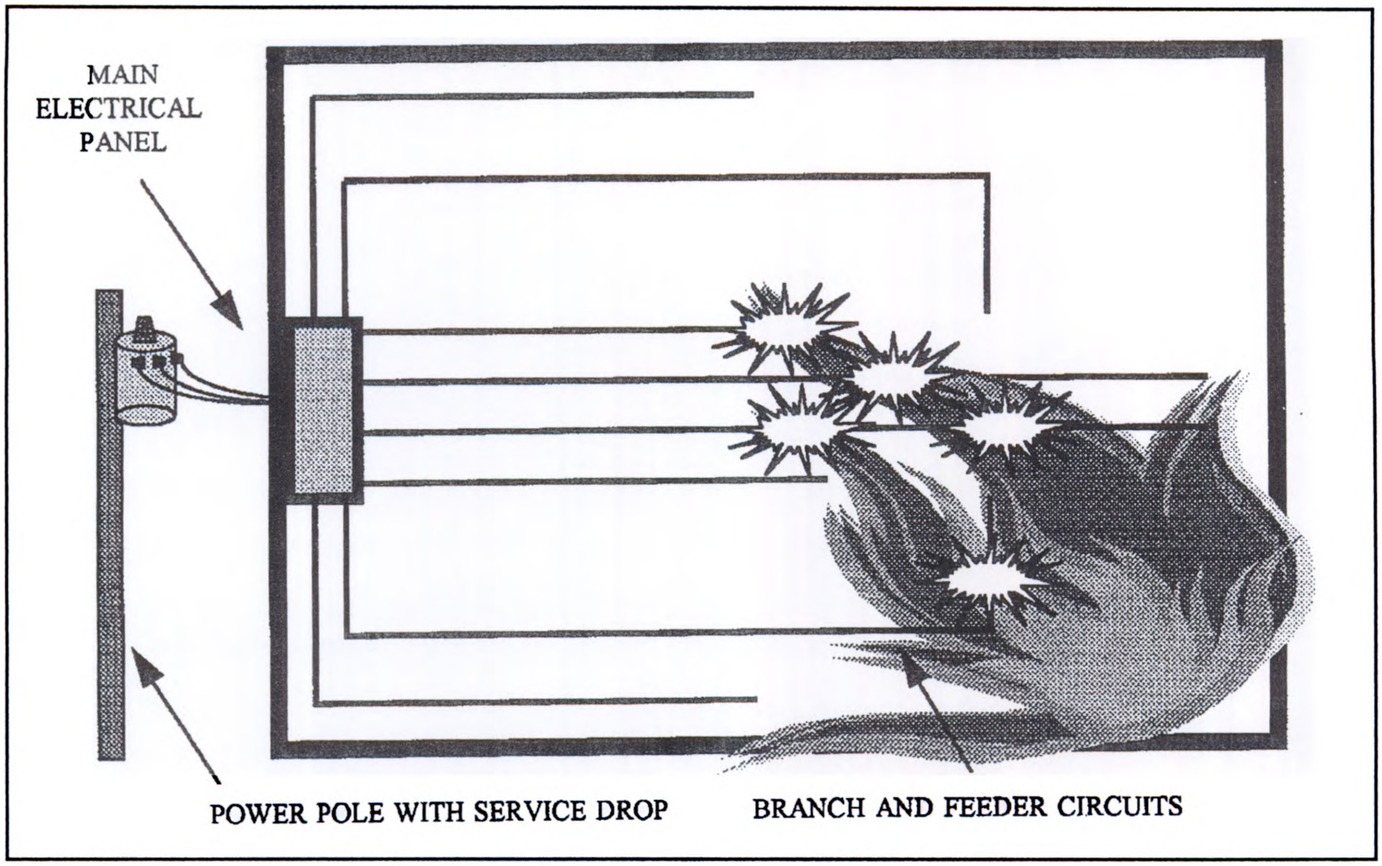

Figure 6a. Fire faults wires closest to the origin.

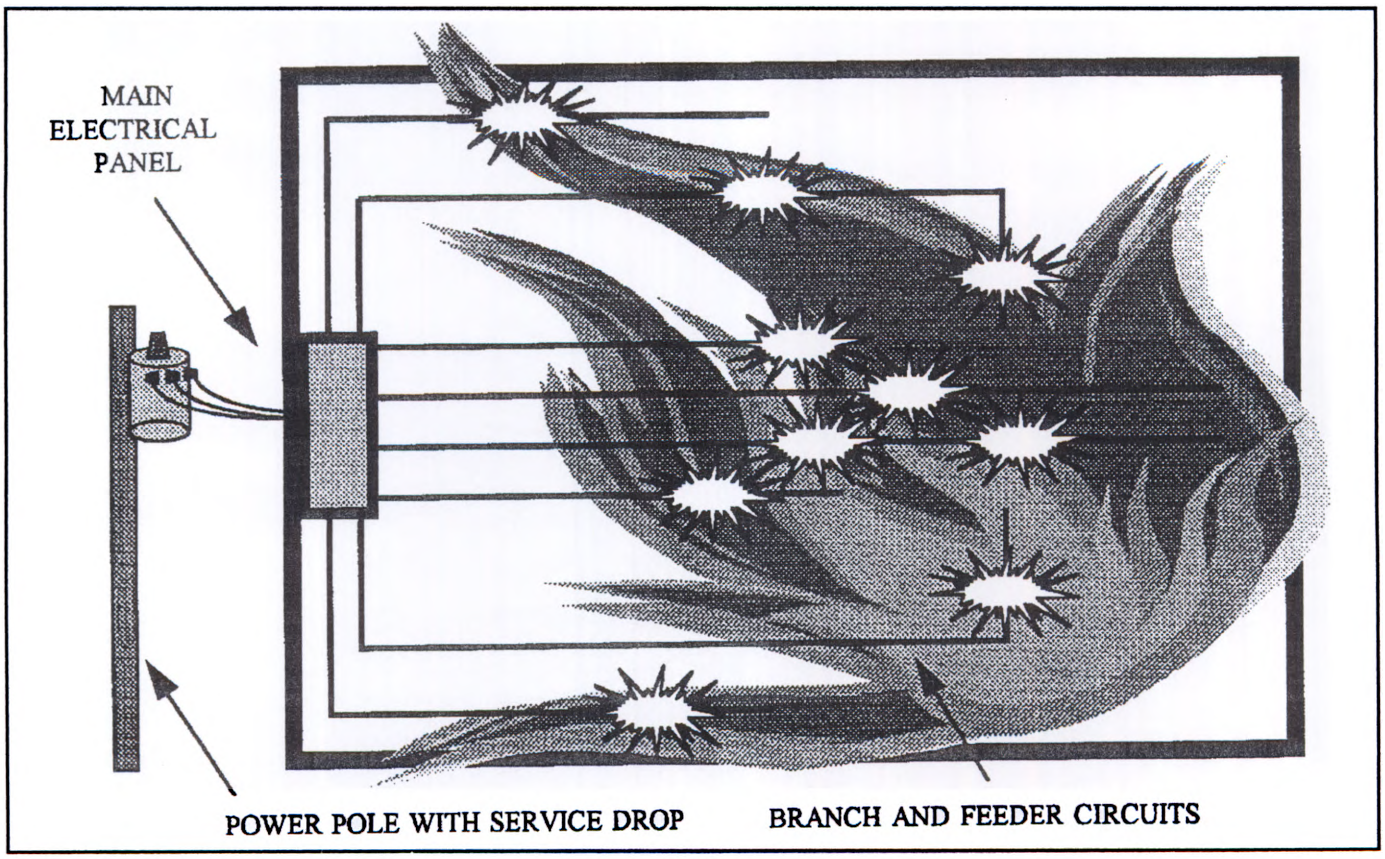

Figure 6b. Faulting damage progresses towards service panel.

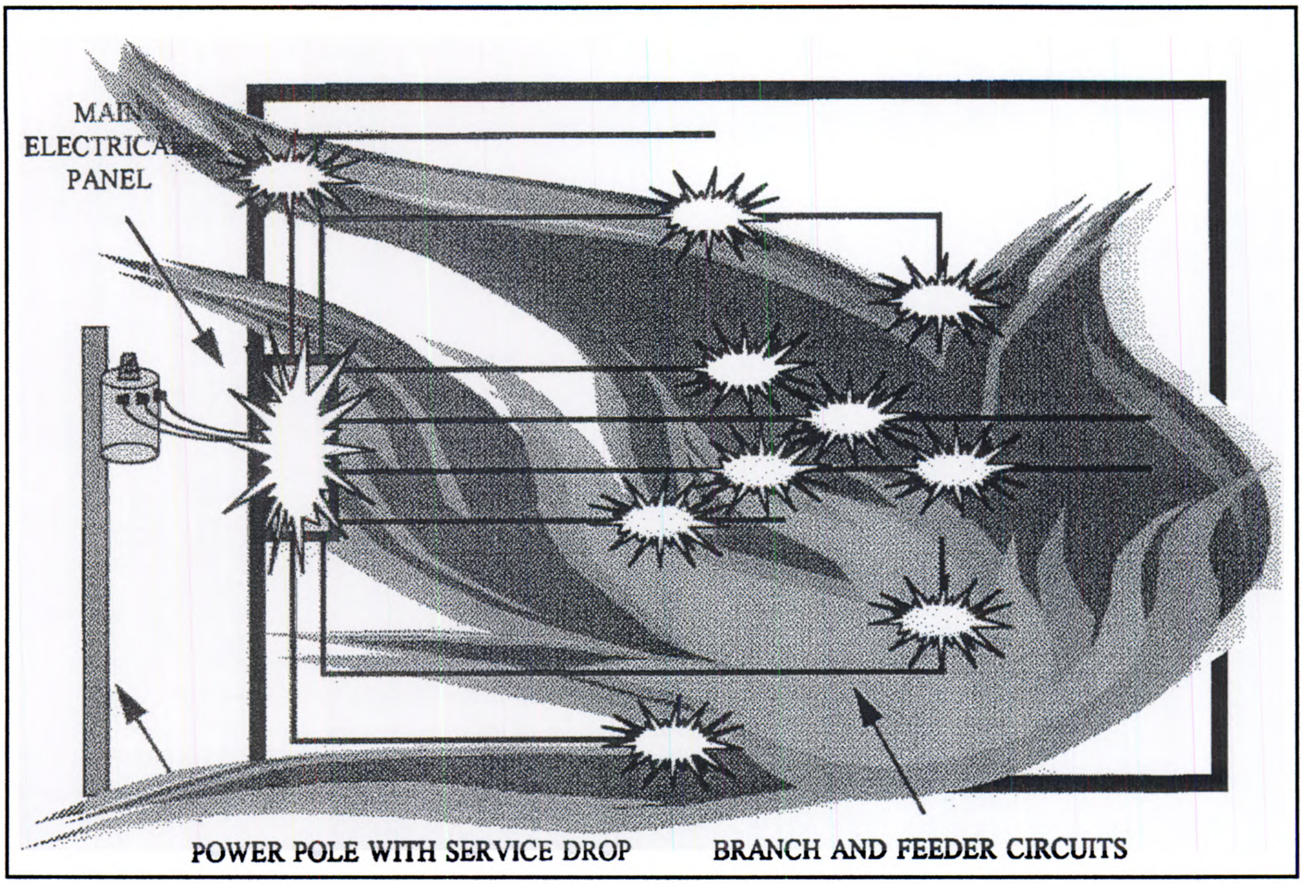

Figure 6c. Service panel is damaged by arcing faults after branch and feeder circuits.

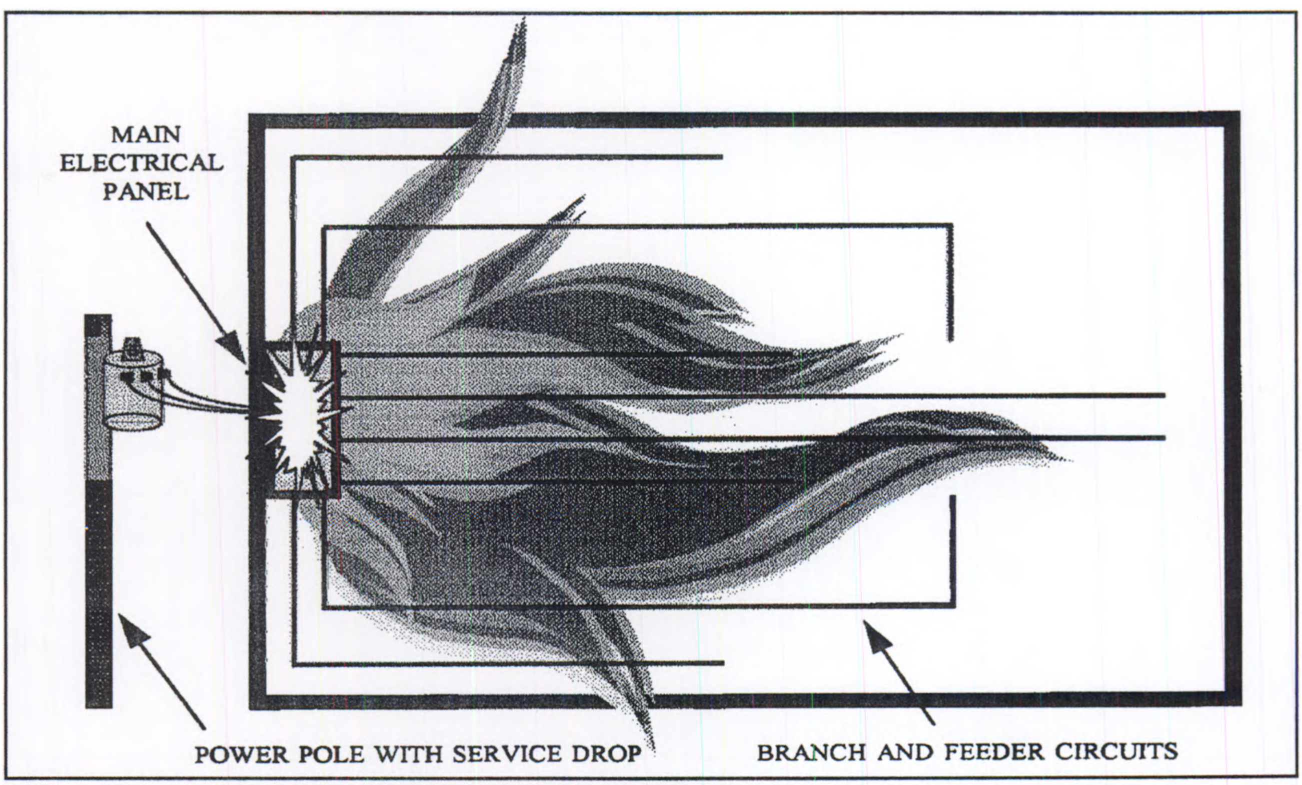

Figure 7. A fire starting inside the service panel interrupts power to the branch circuits so they cannot fault.

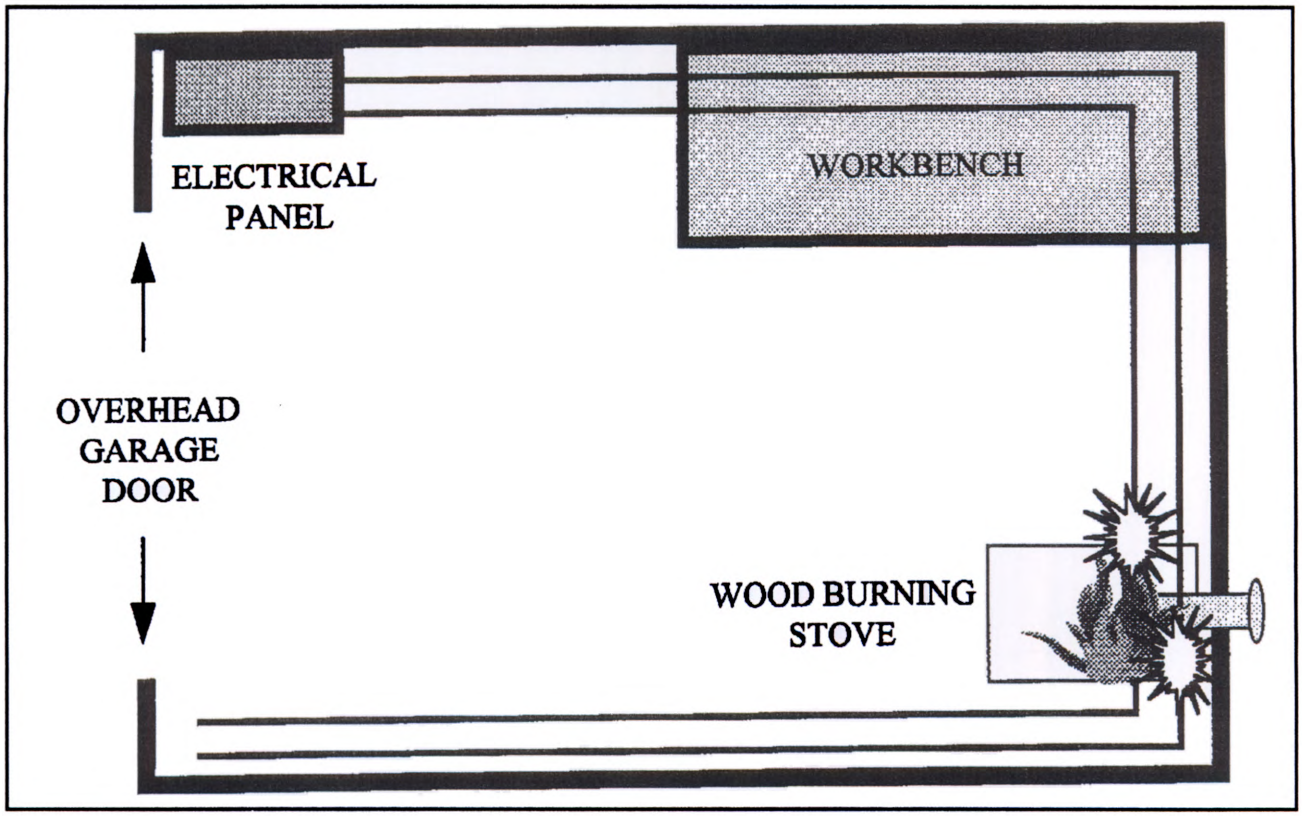

Figure 8. Arcing residue points to origin at wood-burning stove.

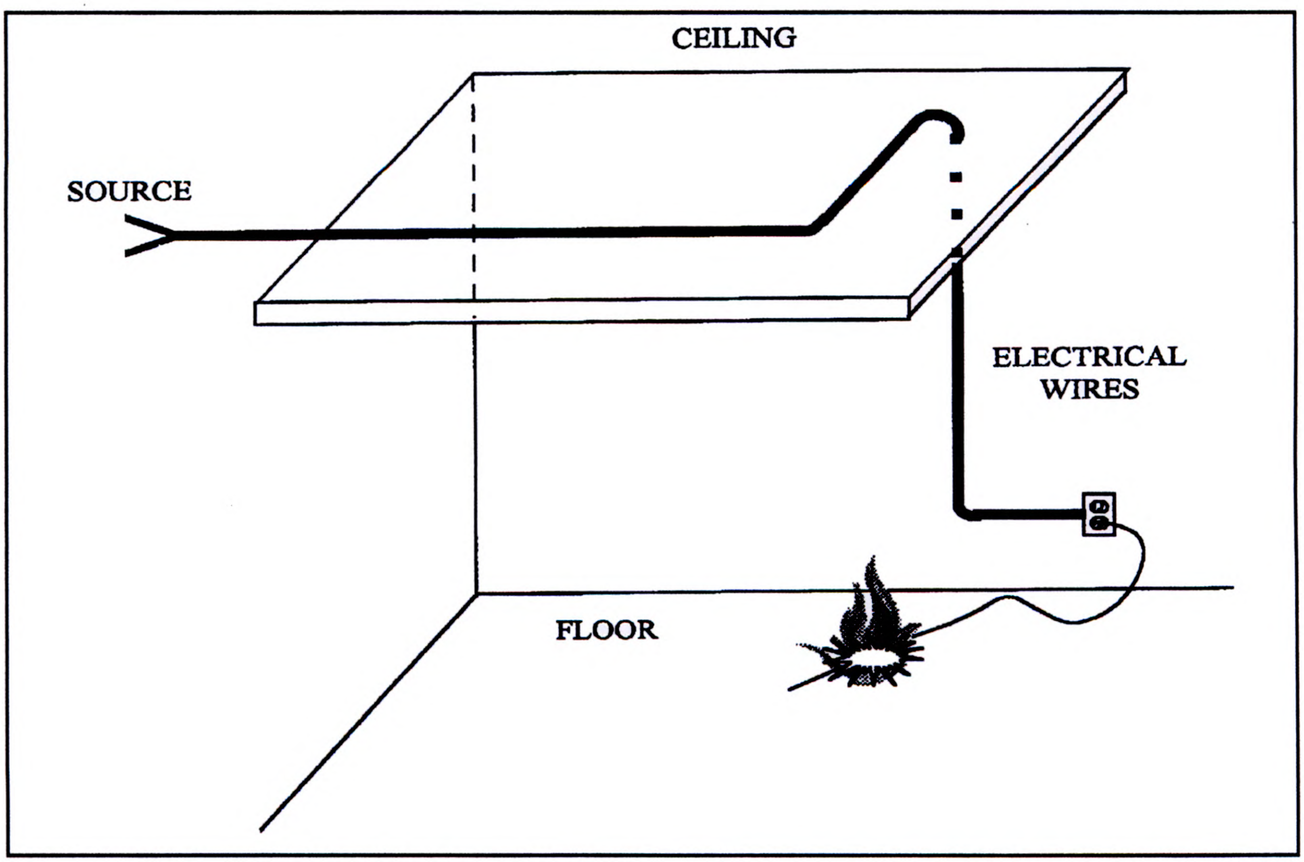

Figure 9. Circuits feeding multiple levels can add third dimension to arcing pattern.

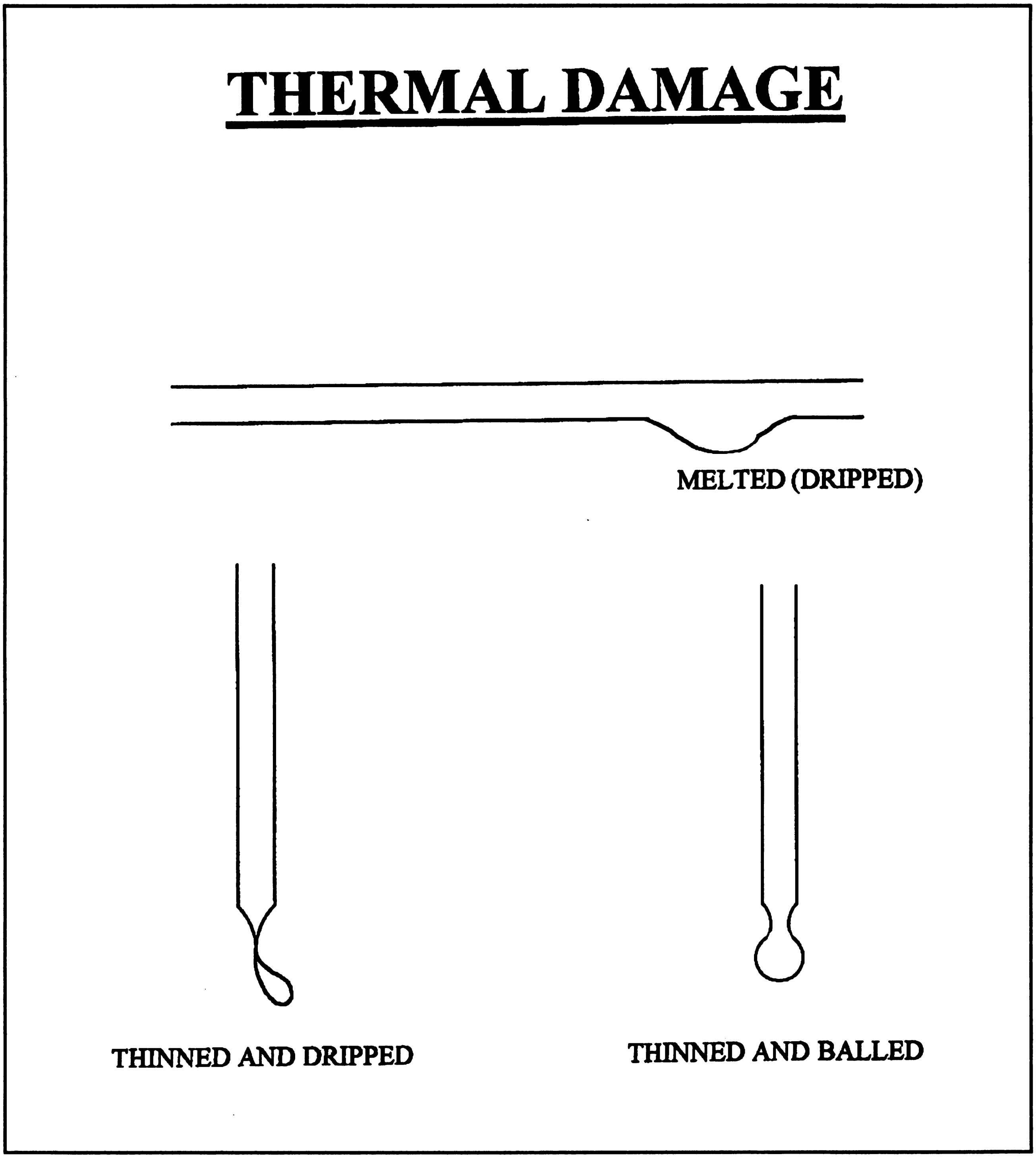

Figure 10. Conductors thinned, sagged, and dripping from the heat of the fire.

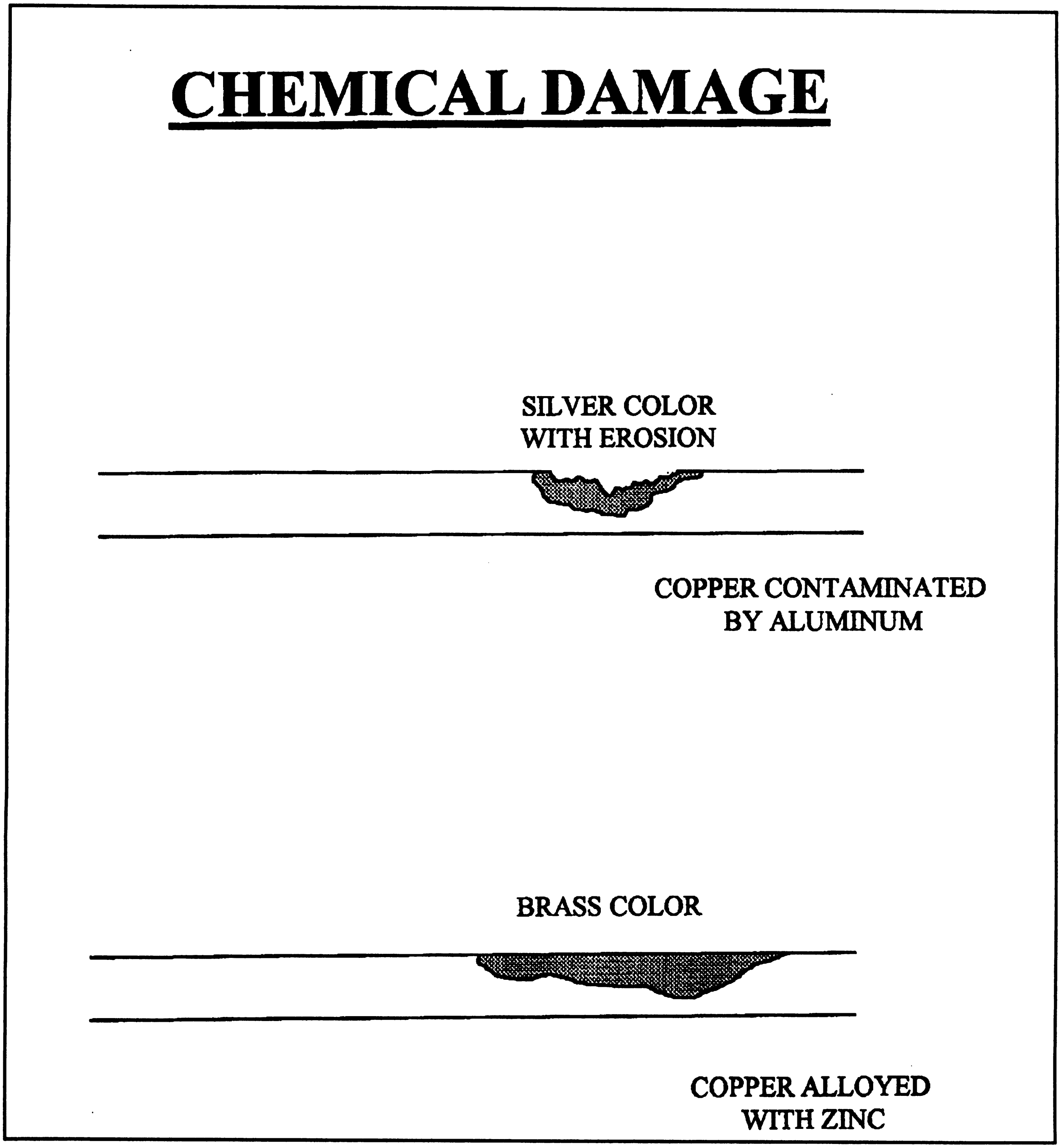

Figure 11. Conductors damaged by chemical reaction with aluminum and zinc.

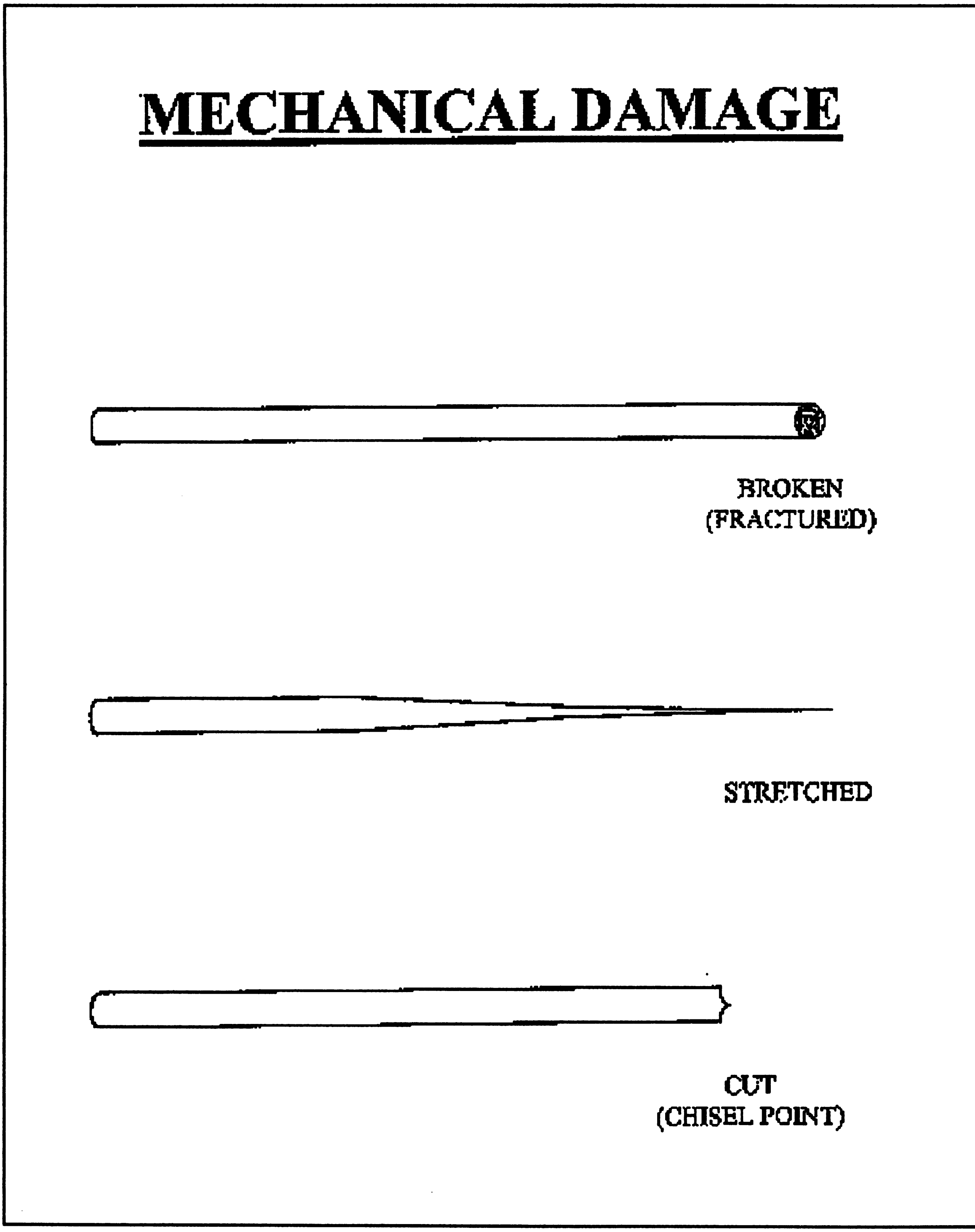

Figure 12. Conductors may be mechanically damaged by friction, pulling, or cutting.

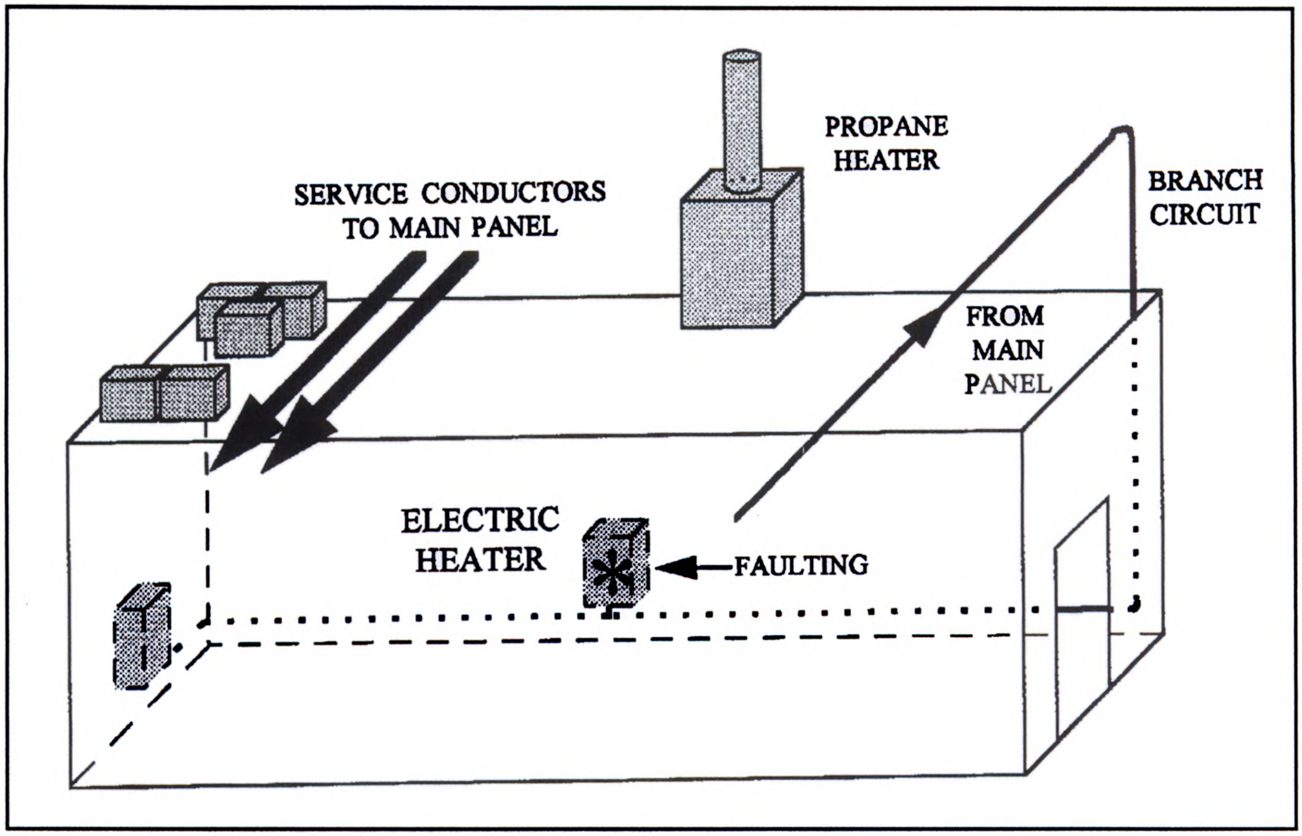

Figure 13. Faulting in electric heater fed by conductors through area of propane heater eliminates propane heater as the fire cause.

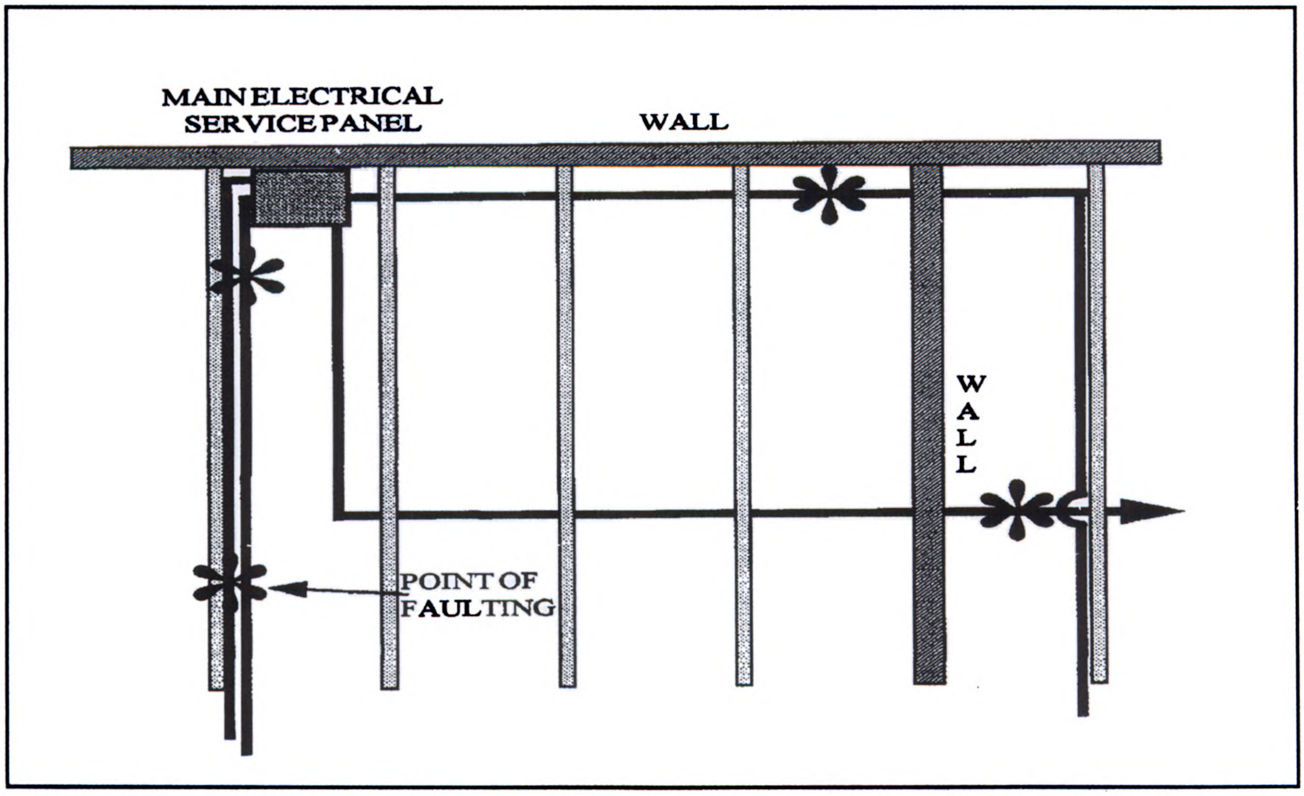

Figure 14. Unconnected points of faulting show abnormal fire progression.

Computer-Aided Scene Drawings

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Communication is the act of making an instance known to others. We are all aware of the fact that verbal communication is subject to misinterpretation. The first supplement to the verbal description of an event was probably a drawing on a cave wall. In most situations, a crime scene drawing can enhance the ability of the investigator to communicate with others, and at the same time diminish the possibility of misinterpretation. The higher the quality and accuracy of the drawing, the more effective the communication effort.

The problem is most investigators do not have the time or luxury to become professional draftsmen. Computerized drawing programs have been traditionally expensive and difficult to use. DesignWare, Inc., of Watertown, MA, has marketed a drawing program that can be used effectively in law enforcement activities. The program is entitled "myHouse" and is sold in both DOS and Windows versions. The program is easy to use and has sophisticated capabilities considering the inexpensive price tag.

The advantages of the program involve its flexibility in selecting elements to be placed in the drawing, the ability to alter the sizes of the elements, and an excellent three-dimensional view capability. It also permits the rendering of surrounding buildings, streets, and landscape elements. The program allows the user to select the height, thickness, and design of walls, doors, windows, columns, rails, and stairs. The program includes four different libraries of symbols. The symbols range from simple boxes and furniture to landscape trees and vehicles. These symbols can be altered as to their respective sizes. Using a little imagination, a circular swimming pool provided in the library with default values of 22 feet in diameter and 2 feet in depth, can be altered to appear 18 inches in diameter with a height of 5 feet, thus resembling a hot water tank. The program allows the user to shift the elevation of the elements and change their orientation. This feature can cause the above-mentioned element to appear as a section of cylindrical duct work.

The most impressive portion of the program involves its three-dimensional capabilities. There are two different ways of generating the three-dimensional views. Once a floor plan is drawn, accessing the three-dimension function results in a wire frame three-dimensional view. This view can be turned in any direction and the view can be developed from different degrees above or below the object. Once the most advantageous view is found, a simple command will execute hidden line elimination and a presentation quality perspective view can be generated.

The second three-dimension function involves placing an image of a camera at a particular position and essentially taking a photograph from that location. This function can be used to simulate the views of eye-witnesses and first-arriving fire personnel. This feature is also valuable in that one wall of a building can be deleted and the camera placed so as to give a representation of the site similar to a cross-sectional view. The height, location, and aperture of the camera can be arbitrarily adjusted to achieve an idealistic view.

The program is capable of automatically inserting dimensions of the structure into the drawing. A "text" function permits the user to place notations on the drawing. The finished floor plans and three-dimensional views can be routed to a printer so that hard copies can be obtained, enlarged, and colored for court presentations. The program is user-friendly and can be learned rapidly. Once a person is somewhat familiar with the program, informative drawings can be done in less than 1 hour. This has

proved valuable in generating drawings quickly for use by interview teams when interviewing eyewitnesses or first-responding firefighters. The three-dimensional views have been found to be of significant value for fire scene investigators, especially when the site involves collapsed conditions. In this situation, the building can be reconstructed, via the program, and viewed in three dimensions from countless angles. This feature is an invaluable aid to spatial visualization problems and allows for an easier way to envision fire progression and egress problems.

The versatility of the program involves a "paint" function which applies solid colors to sections of the drawing. Once a desirable representation has been obtained, it can be saved as a "picture." This allows for an instant recall of the desired view in full color. A "retouch" function permits the use of a theoretical paint brush, in a user-selected color, to alter or insert patterns on the painted drawing.

This program cannot only be used to generate hard copy drawings for courtroom presentations, but it can be theoretically used with courtroom monitors to present different angles or views of potentially any crime scene. The angles of these views can be adjusted dependant on the point being made or the physical position of witnesses.

Fire Debris Analysis and Accelerant Concentration

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Most forensic science services in Canada are provided by the six Royal Canadian Mounted Police (RCMP) Forensic Laboratories. These laboratories are located in Vancouver, British Columbia (covering British Columbia and the Yukon Territories); Edmonton, Alberta (covering Alberta and the western half of the Northwest Territories); Regina, Saskatchewan (covering Saskatchewan); Winnipeg, Manitoba (covering Manitoba and the eastern half of the Northwest Territories); Ottawa, Ontario (covering the area around metropolitan Ottawa and providing a centralized operational support function); and Halifax, Nova Scotia (covering the four Atlantic provinces). In addition, the Center of Forensic Science in Toronto and their regional laboratory in Sault St. Marie covers Ontario and the Direction des Expertises Judiciaries in Montreal covers Quebec. The six RCMP laboratories each have six sections providing a distinct forensic service, namely alcohol, biology, chemistry, documents, firearms, and toxicology. Four of the laboratories also have a Forensic Identification Support Section providing expertise in blood splatter calculations and the identification of human remains and bones. The Central Forensic Laboratory in Ottawa also has a separate research and development component which provides assistance and resources to all laboratories.

Within each RCMP laboratory, the Chemistry Section is structured around four core areas of analysis, although the total casework mandate is quite broad. The four core areas are paint examinations of all sorts (*e.g.*, hit-and-run accidents, breaking-and-entering investigations), glass (*e.g.*, breaking-and-entering investigations), fibers (*e.g.*, assault and bodily harm investigations), and fire debris (suspicious fire investigations). Additional specialized services such as explosive analysis have been centralized into certain laboratories.

In suspicious fire investigations, the primary purpose of the Chemistry Section is to assist the fire investigator in determining the cause and origin of a fire which resulted in the destruction of property and/or bodily harm. This assistance is usually in the form of the analysis of fire debris related to a suspected origin for the presence of any liquid which may have been used as a fire accelerant. The Chemistry Section will also analyze exhibits suspected of being related to the cause of the fire (*e.g.*, Molotov cocktails), as well as conducting other examinations as required and identifying outside resources if the expertise is not available in the section or laboratory. Assistance to investigators in suspicious fire investigations represents 20.2% of the caseload conducted by the RCMP Chemistry Sections.

As reflected by a review of the forensic literature spanning the last 40 years, developments and improvements in the methodologies and instrumentation within the RCMP laboratories have paralleled those in the field of fire debris analysis. Early methods of recovery of flammable and combustible liquid residues from fire debris in the 1950s through to the 1970s included immiscible-phase flotation, solvent extractions using petroleum ether, simple distillation, steam distillation (including the Macoun and Brackett variations), and vacuum distillation using successive ice and water, brine, and dry ice in acetone cold traps (Coldwell 1957; Macoun 1952). All of these methods were labor intensive and resulted in poor to medium recoveries. In the early 1970s, solvent extractions were developed using either n-pentane, diethyl-ether, or acetone as the extractant of choice. After successive washes of the fire debris, the solvent portions were combined, filtered through an activated alumina column, evaporated down, and analyzed by packed column gas chromatography. In the mid-1970s a static headspace analysis using a 1 to 2 milliliter headspace volume was developed,

primarily as a screening procedure. Also at this time, packed column chromatography (such as 6' Dexsil 300 and 26' Tandem SE-30 columns) was gradually being converted to capillary chromatography, with a 12-meter SP-2100 capillary column being one of the first such columns. The early 1970s also saw the development of an improved vacuum distillation apparatus at the Regina Forensic Laboratory using liquid nitrogen as the coolant (Hrynchuk *et al.* 1977). By the end of that decade, three general methods for the detection of accelerants in fire debris were employed in the RCMP Forensic Laboratories—static headspace, solvent extraction, and vacuum distillation—and all were methods of analysis which would be in use for several years.

In the late 1970s to early 1980s, the evaluation and development of the Curie point pyrolysis system (Twibell and Home 1977; Twibell *et al.* 1981) resulted in the use of an equivalent Curie point pyrolysis system in the RCMP laboratory system (Hrynchuk 1983) which remained the "workhorse" analysis method in our Regina laboratory until 1988 when parts were no longer available. Our first attempt at a "purge-and-trap" analysis was in 1981 when the Edmonton laboratory experimented with aspirating heated vapors from fire debris through a pyroprobe tube containing activated charcoal and thermally desorbing the volatiles onto a 2-meter OV-1 column (Buckle and Lambertus 1981). Towards the end of the 1980s all of the RCMP laboratories had developed one or both of two general types of analysis. In one method, commonly known as purge-and-trap or adsorption/elution, either commercially available charcoal tubes (ORBO® -32 charcoal tubes, Supelco Chromatographic Specialities) or homemade charcoal tubes (typically a Pasteur pipette containing 2.5 centimeters of 200-mesh activated charcoal sandwiched between glass wool plugs) were sealed into holes punched into fire debris containers or connected in line with tubing to the container. The container was then heated and the volatiles drawn through the charcoal adsorbent with a small pump. In the second method, known as passive adsorption, a layer of bulk charcoal granules (Supelco Chromatographic Specialities) were spread over the bottom of an open glass vial which was sealed in the container with the fire debris and heated for 1 - 2 hours. In 1988 the charcoal granules were replaced with a Pro-Tek® charcoal strip originally developed for use in the occupational health and safety field. The charcoal adsorbents were extracted with carbon disulfide (1 milliliter which was concentrated down) and analyzed by gas chromatography. These new methods had many advantages over the older established methods, including shorter analysis times, enhanced sensitivity, the possibility of replicate analysis as carbon disulfide extracts, and the methods were less labor intensive.

Over the last few years, these dynamic and passive methods of fire debris analysis have been constantly reviewed and improved upon. As part of the RCMP ongoing quality assurance mandate, the Chemistry Sections adopted the ASTM fire debris methods (ASTM E1412-91 Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Dynamic Headspace Concentration; and ASTM E1413-91 Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Passive Headspace Concentration) as the standard for national compliance. Also the reporting of results in fire debris submission (including the flammable and combustible liquid classification scheme originally proposed by the National Bureau of Standards and the Bureau of Alcohol, Tobacco and Firearms) was adopted. This is now the ASTM E1387-90 Standard Test Method for Flammable or Combustible Liquid Residues in Extracts from Samples of Fire Debris by Gas Chromatography. This classification scheme divided flammable and combustible liquids into five classes based on the equivalent n-alkane carbon number range with an additional unclassified category to accommodate those liquids which do not meet the criteria of the five classes. Also as part of our quality assurance mandate, the RCMP laboratories are active participants in the Collaborative Testing Program, including successfully completing several CTS Flammable proficiency tests over the last few years. Regular internal proficiency tests are also conducted among the Chemistry Sections in all core examination areas, including fire debris analysis.

Currently, our research and development in the field of fire debris analysis is focused on two areas. Several years ago the Canadian military designed and developed an automated thermal analysis system for the detection of chemical warfare agents (Hancock *et al.* 1991). The instrumentation was manufactured by the Saskatchewan Research Council in Saskatoon, Saskatchewan, and tested at the Defense Research Establishment in Suffield, Alberta. This system consists of two components comprising of the field component, which automates the collection of air samples in the environment being monitored (*e.g.*, battlefield), and the laboratory component which automates the analysis of the field samples. The link between the field and laboratory components is a tenax adsorption tube which measures 38 mm x 2 mm (id), contains 14 milligrams of tenax, and is stored in a carousel which can hold 50 adsorption tubes. The carousel is initially loaded into an air sampler in the

field for sample collection and then subsequently transported to the laboratory and loaded into an auto-sampler called an automated thermal desorption unit (ATDU) for analysis by gas chromatography. An initial evaluation of this system for fire debris analysis using a passive headspace method (Verrett and Proulx 1993) was encouraging in showing a recovery of petroleum products over a wide boiling range and a wide concentration range without the use of cryogenic focusing. The procedure consisted of the following steps:

- Placing a tenax adsorption tube in a clean beaker which was then placed in the container with the material being analyzed;

- Sealing the container and heating it at 100°C for 1 - 2 hours;

- Cooling the container at room temperature for 15 - 20 minutes before removing the tenax adsorption tube; and

- Loading the tube into the carousel together with other sample tubes for automated analysis by gas chromatography.

In addition to the recovery of petroleum products over a wide boiling/concentration range, other advantages of the ATDU procedure included portability and compactness (the carousel measures 9 cm [dia] x 5 cm [deep] and holds 50 adsorption tubes), no cryogenic focusing, minimal dead volume, no solvent use, and a large throughput of samples with 50 adsorption tubes in the carousel. However, there is one major disadvantage with this system. When stored in the carousel, the ends of the adsorption tubes are not sealed and bleed from one tube has been shown to contaminate adjacent tubes. The manufacturer is aware of this problem and is currently developing a carousel seal with assistance from the Forensic Laboratory.

The second area of research and development is also directed towards a passive method. With the introduction of the DFLEX® (Diffuse Flammable Liquid Extraction) device from Albrayco Materials Analysis Laboratory at the 1992 AAFS Convention in New Orleans, the RCMP is in the process of developing a methodology for using these devices, which will be similar to the procedure used with the Pro-Tek® strips initially used in 1988. The DFLEX® device consists of a charcoal strip enclosed in a protective membrane and metal jacket and is advertised for use both at the fire scene and in the laboratory. A proposed analysis scheme (Figure 1) for the examination of fire debris by charcoal strips was presented at the 1994 Canadian Society of Forensic Science Conference in Vancouver. This analysis scheme is currently being reviewed by the RCMP Chemistry Sections and will be published, tentatively next year, after peer testing as a passive headspace methodology. All RCMP laboratories have been experimenting with different conditions for the DFLEX® device and the proposed analytical scheme is a compilation of these experiments. This proposed analytical scheme includes both the Pro-Tek® strip and the DFLEX® device. The DFLEX® device is sturdier and less prone to contamination because it is enclosed in a metal jacket and sealed in its own protective envelope. The Pro-Tek® charcoal strip is less expensive because it can be purchased in bulk, but it does not have a protective membrane or jacket.

The initial visual examination of the fire debris sample will identify any suspicious or significant foreign materials (*e.g.*, melted candle wax or powder residue) as well as any strong odors such as a petroleum product odor which may affect the analysis. For long-term health reasons, however, there should be no conscious effort to smell the fire debris. The charcoal strip is then sealed in the exhibit container with the sample of fire debris. A DFLEX® device is removed from its protective envelope and directly placed in the container while a Pro-Tek® strip is either suspended above the sample or placed in a new glass vial (*e.g.*, 15-milliliter screw-cap vials, Fisher Scientific Company) and sealed in the container.

The container is then heated for 2 hours in a 100°C oven. The 2-hour time frame is required to allow the container and contents sufficient time to heat up to 90°C (Sandercock 1992) as per the requirements of ASTM E1413-91. Although longer heating times at lower temperatures have been used, for example 16 hours at 60°C, a number of problems have been encountered with longer heating times and lower heating temperatures. There are safety and contamination concerns with heating exhibit bags and cans in the oven overnight because these types of containers are more prone to ruptures and leakage. Exhibit bags and cans are very popular among fire investigators—in the Regina Forensic Laboratory, 75% of fire debris samples are received in exhibit bags and cans. Also, over a wide range of petroleum product standards, no appreciable differences were found in the chromatogram profile when heated overnight or for 2 hours at 90°C, although the heavier petroleum products did show a greater recovery when heated for the longer time. The heavier petroleum products also require heating at higher temperatures for the recovery of the higher boiling components.

Analysis Scheme - Charcoal Strip Analysis for Fire Debris
1) Examine and document the fire debris sample. - Identifies any obvious odors which may affect analysis. - For health reasons, there should be no conscious effort to smell the fire debris. - Raises concerns over loss of volatiles.
2) Open a charcoal strip and seal in fire debris container. - DFLEX® device - open metal foil. - Pro-Tek® strip - place in vial.
3) Heat container in oven set at 100°C for 2 hours. - Containers take up to 1 hour to reach 90°C. - Batching of exhibits takes longer time to reach 90°C. - Allows for greater turnaround of samples. - Eliminates concerns with overnight heating. - The presence of any petroleum odors identified (in #1 above) will reduce the time and/or temperature of analysis.
4) Remove container from oven and cool for a minimum of 15 minutes. - Safely reduces pressure buildup in containers. - Full face shield, oven mitts, and lab coat must be worn for safety. - Minimizes condensation (Pro-Tek)®.
5) Remove charcoal strip from container and seal in clean vial. - Use original vial for Pro-Tek®. - Cut open membrane for DFLEX®.
6) Extract charcoal strip with 0.2 - 1 mL carbon disulfide and analyze. - Extract for 5 - 30 minutes. - Use a minimal amount to ensure complete wetting of strip; amount depends on glass vial used. - Allows flexibility if petroleum odors are identified.

Figure 1.

After removing from the oven and cooling for 15 - 20 minutes to reduce the pressure in the container and minimize condensation (if the Pro-Tek® strip is used), the charcoal strips are extracted with carbon disulfide for a few minutes and analyzed by gas chromatography. Extraction and analysis of blank charcoal strips in studies (Demers-Kohls *et al.* 1994) and in casework is routinely conducted to monitor background profiles.

The field use of the DFLEX® device as advertised by the manufacturer is also being evaluated by the Forensic Laboratory, primarily for use on those samples from the scene which are difficult to recover and submit to the laboratory (*e.g.*, concrete floors). Preliminary studies in which unopened DFLEX® devices were stored in vehicle trunks for up to several weeks have shown no contamination of the strip. This study was done to simulate long-term transportation and storage in police and fire department vehicles. Under extreme conditions, however, it has been shown that the protective envelope in which the DFLEX® device is stored is not completely sealed. A sealed DFLEX® envelope was suspended above 4 milliliters of gasoline in a 1-liter mason jar at room temperature for 2 days—when the charcoal strip was carefully removed and extracted, it showed a strong gasoline profile. The next step in the field evaluation is to have fire investigators use the DFLEX® device for the samples they collect at the scene. Once submitted to the laboratory, dual DFLEX® analyses would be conducted on these samples to compare results.

What does the future hold for fire debris research and development within the RCMP Laboratories? Definitely the continued development of the Pro-Tek® and DFLEX® charcoal strip methodology. Definitely the continued evaluation of the field use of the DFLEX® device for *in situ* exhibits and for exhibits submitted to the laboratory. Definitely the continued move towards automation, both for thermal desorption systems (ATDU) and for solvent desorption systems utilizing the charcoal strips. After incorporating auto-samplers into the analysis procedure, possibly the next step may be to connect a commercial preparation station to the front end of the auto-sampler in order to automate the extraction procedure. The future also shows continued cooperation between laboratory systems across state, provincial, national, and international borders as represented by this symposium on the forensic aspects of arson investigations.

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Analytical Automation Technologies

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Every year analysts are asked to process more arson cases with less time and money. A more efficient way must be found to accurately process this increasing volume of arson samples. In order to be able to meet current and future caseload demands, automated fire debris analysis will have to be incorporated into laboratory procedures. For rapid reporting, automatic analytical results will be generated for review by the analyst. By using automated arson analysis technology, an analyst will rapidly and accurately identify accelerants extracted from fire debris.

The State Law Enforcement Division (SLED), located in Columbia, is the primary law enforcement agency for the state of South Carolina. SLED is composed of multiple law enforcement departments. One department, the Forensic Sciences Laboratory, is composed of 13 forensic disciplines. One of these is the arson laboratory that conducts all forensic analysis of fire debris samples submitted by law enforcement personnel statewide. In addition, SLED has 16 full-time arson investigators strategically stationed throughout the state.

As the sole forensic laboratory for the state, the volume of submitted arson evidence necessitates automated evidence processing. Laboratory automation begins with the batch processing of multiple cases (depending on the number of samples per case). Arson cases are processed daily using the adsorption/elution carbon strip method to generate a batch of 10 to 12 sample vials. Each sample vial is labeled with the laboratory file number and a description of the sample container (*e.g.*, L95-00001 Can #1). The vials of carbon disulfide, plus any extracted volatile organic compounds, are placed in a Perkin-Elmer AS2000B automatic liquid sample injector. Using a computer, a method is chosen to control the gas chromatograph and autosampler. The known series of alkanes, C7 - C17, a dilute gasoline standard, and blank solvent vials are included in each batch analysis. Carbon disulfide vials are placed as solvent flushes between each sample. Batch samples are usually processed overnight. The following day, data and chromatograms are evaluated. The majority of the chromatograms are identifiable using direct visual comparison to known standards. The chromatograms that resemble known accelerants are scheduled for analysis by the gas chromatograph/ mass spectrometer (GC/MS). Chromatograms that are off-scale or indicate minimum signals will be reinjected into the gas chromatograph after dilution, concentration, or reprocessing using an alternative procedure.

There are four major areas of arson analysis: sample preparation/extraction, instrumental analysis, data handling, and report writing. Of the four areas mentioned, three are currently automated. The sample preparation/extraction area has proven to be the most difficult to automate, and it will be discussed last. A brief discussion and summary of each section follows.

AUTOMATED INSTRUMENTAL ANALYSIS

The instrumental analysis of arson samples has been greatly enhanced by the use of autosamplers. This instrument allows an unattended, variable volume, injection of multiple samples. There are many different manufacturers of autosamplers. The Perkin-Elmer AS2000B manufactured by the Perkin-Elmer Corporation (Norwalk, CT), and the Hewlett-Packard 7673A manufactured by the Hewlett-Packard Company (Palo Alto, CA) are used in this laboratory. Both autosamplers can process up to 100 sample vials. These glass vials have crimp-sealed caps containing Teflon-coated septum.

The AS2000B is a microprocessor controlled, multisampling, pneumatically operated, automatic preset volume injection system. The instrument uses a continuous loop belt magazine to transport 8 mm sample vials. The magazine can contain up to 50 samples with carbon disulfide solvent as blanks between each sample vial. The sampling and injection parameters are variable. There are sensors in the magazine to track vial sequence and scan for missing vials.

The Hewlett-Packard 7673A has a motorized automatic sample injector, which is computer controlled. The injector tower has a syringe transport system and positions for five vials (two solvent, two waste, and one sample position). The tower is programmable for random sample injection and variable flush cycles. Four 25-sample-trays surround the tower. The sample vials are 11 mm (outer diameter) with a maximum volume of 2 ml. A robotic arm transports the sample vials from the tray to the tower for injection. A barcode reader (optional) is an excellent tracking device, particularly for chain-of-custody documentation.

AUTOMATED DATA HANDLING

For the laboratory using only a computer-assisted gas chromatograph for arson analysis, a software package called Matchfinder© is a good starting point. It is manufactured by AEA Technology, Harwell Laboratory, in Didcot, Oxon, UK. The program was evaluated by Koussiafes and Bertsch (1993). The Matchfinder© program allows for an unknown chromatogram to be compared to an internal library of known standards. The program uses algorithms to correct for changes in retention time and peak intensities and then makes key peak matches.

For the laboratory using a GC/MS, the use of target compound chromatography (TCC) will provide additional analytical capabilities. Keto and Wineman (1991) described the generation and utilization of TCCs. The TCC is a reconstructed chromatogram identifying retention time and relative concentration for each target compound. By using the TCC process, the veil of background peaks is parted for a clearer view of minute levels of accelerants.

In a recently published article, Keto (1995) compared target compound analysis with mass chromatography or ion profiling. Ion profiling is shown to create problems when only a few selected ions are profiled. A major difficulty is that ion profiling cannot distinguish whether the ions detected are from petroleum compounds or from pyrolysis products.

In the newer process, target compound analysis cleans up the ion profiles by filtering out superfluous data. The daughter ion's ratio relative to the base ion of an accelerant compound, along with the compound's retention time, focuses the chromatogram on the important peaks of interest.

The three limitations of target compound analysis are: first, the limited number of comparison points; second, lower sensitivity; and third, an increased likelihood of false negative results.

In conclusion, both techniques should be applied to sample chromatograms that exhibit high backgrounds or complex irregular patterns. This will allow the analyst maximum information about the samples and provide valuable assistance in attaining an appropriate conclusion.

AUTOMATED REPORT WRITING

The automated system used to generate an arson laboratory report at SLED is known as SLIMS® (State Laboratory Information Management System). SLIMS®, owned by AG Communications (Phoenix, AZ), also performs evidence tracking and handling. Prior to the generation of the final laboratory report, the analyst reviews the sample preparation/extraction, instrumental analysis, and chromatographic results for errors. Following separation of positive and negative samples, the results are recorded on a laboratory worksheet. The SLIMS® computer work screen is accessed using the laboratory file number, and a work option is chosen. One work option is "qwork" (quick work), which is an expeditious way of generating a formal report. After selecting a submitted item of evidence, the computer screen allows a choice of structured classifications:

- No flammable or combustible liquids detected.
- Gasoline found.
- Light petroleum product found. Examples are lacquer thinners, lighter fluids, camping fuels, ...
- Medium petroleum product found. Examples are some charcoal starters, paint thinners, ...

- ♦ Heavy petroleum product found. Examples are some charcoal starters, kerosene, fuel oils, ...

NOTE: When an unusual or a single-component accelerant is identified, the results may be entered using the modify case notes option.

After matching all submitted items with correct results, the final report is viewed on screen and modified as necessary. The report is then electronically transmitted across the network to a personal computer database. Here, the document is retrieved via the laboratory file number and is reviewed for spelling and grammatical errors. If the document is correct, the report is printed. After the analyst reviews and signs the report, it is mailed to the requesting agency. A copy is maintained in the case file.

AUTOMATED SAMPLE PREPARATION

Many formidable challenges stand in the way of automated sample preparation, but they can be conquered.

The first step is to think about how robots currently perform sample preparation and adjust procedures to match the robot's capabilities. The second step is to identify the possible problem areas and propose solutions. The third step is to implement these solutions using existing robotic technology.

Automated sample preparation has been applied successfully to other scientific disciplines. Two of the SLED forensic science departments currently use Zymark robots, manufactured by Zymark Corporation (Hopkinton, MA) for sample preparation. The drug analysis department uses two robots to extract controlled substances from powders and tablets. The toxicology department has two robots to extract controlled substances from body fluids, and one robot to process urine samples for controlled substances. All robotic sample preparation results in sample vials for injection into a GC/MS instrument.

Thomas (1994) discusses the application of three Zymate robots to sample preparation. One robot is used to process oil samples for polychlorinated biphenyls. The robot weighs, dilutes, and performs a liquid extraction on oil samples. After sample preparation, the vials are injected into a gas chromatograph for analysis.

Currently, there are three major obstacles to the automation of sample preparation and extraction:

- ♦ The standardization of a sample debris container.
- ♦ Suitable sampling procedure that is compatible with robotics.
- ♦ The injection technique of nonliquid samples into the gas chromatograph or GC/MS.

The standardization of containers for the collection and preservation of arson debris presents many challenges.

Each type of container currently used has its own unique advantages and disadvantages. After many years of experience with all types of containers, a lined quart "paint" can is best suited for automation. A metal paint can allows for rapid heat transfer. It is unbreakable and easily sealed. It is also readily obtainable and inexpensive. The most significant advantage of the paint can is the availability of commercially manufactured lids containing septum. These lids containing septa can be penetrated by a needle for automated sample extraction.

A method using evacuated sample tubes, has been automated by the Bureau of Mines. The sample tubes, containing air from mine shafts, are placed on a robotics platform. The tubes are sequentially injected into a gas chromatograph (Ms. Marsha Paul, Zymark Corporation, personal communication).

There are several possibilities to solve the obstacles of automatic sample preparation. Nonliquid sample introduction into a GC/MS poses logistical problems. One area that has been automated is the solventless injection of volatile organic compounds. Karkkainen *et al.* (1994) describes the adsorption of gasoline on a TENAX® tube. This procedure uses a TEKMAR 5010 GT automatic thermal desorber, manufactured by Techmar, Incorporated (Cincinnati, OH), for the elution of volatile organic compounds. Two cryogenic-focusing units are used to introduce samples into the GC/MS. Although there are disadvantages to this procedure, such as manual sample manipulation, it is an automatic injection technique.

Another possibility, mentioned in Supelco Application Note 61 (1994), is the process of solid phase microextraction (SPME), which could be

integrated into a robotics procedure. SPME uses a polydimethylsiloxane coated on a fused silica fiber to adsorb and elute volatile organic compounds. The silica fiber is contained within a special holder that is thermally heated to desorb the compounds directly into a GC/MS.

An automated robotics system using SPME could operate in the following manner. The sample rack contains previously prepared quart cans. The old lids from the cans have been replaced with the new ones containing septum. A barcode strip is added to each can for evidence tracking. A computer is initialized and a program is activated. A robotic arm moves the first can from the sample rack to the barcode station. The barcode number is recorded by computer. The can is then placed in the heating station for an appropriate time. The robotic arm retrieves a syringe containing an SPME-coated fiber. The robotic arm penetrates the sample container septum with the SPME syringe and allows adsorption of volatile organic compounds. After an appropriate time, the robot introduces the syringe into either a cryogenic unit or a thermal desorption device interfaced to the injection port of the GC/MS. The adsorbed compounds are desorbed into the GC/MS injection port. The syringe is placed in a thermal desorber station for decontamination. Data and chromatographic results are processed by the controlling computer, followed by report generation. The cycle is repeated again for the next sample.

CONCLUSION

By solving the problems of automated sample preparation and data manipulation, a totally automated system is possible. The use of automated analytical technologies will increase sample throughput and precision. Using existing technology, a combination of target compound chromatography and/or extracted ion profiling will allow a confident identification of complex arson chromatograms. The future of arson analysis can be found in the direct extraction of volatile organic compounds from fire debris, combined with automatic chromatographic analysis and automatic report generation.

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Recent Advances in Gas Chromatography/Mass Spectrometry of Suspect Arson Samples

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The determination of residual accelerants in fire debris is perhaps one of the most challenging tasks in the entire field of forensic analytical chemistry. Typical debris from a fire scene consists of a mixture of both organic and inorganic materials which are usually charred and often contain copious amounts of water. Accelerants can range from solid oxidizers to complex mixtures of synthetically produced hydrocarbons. The number of potential accelerants is almost without limit. Changes in the composition of an accelerant during exposure to a fire further complicates the matter. The most difficult task, however, is to discriminate the accelerant-type compounds originating from an accelerant from those generated by the background. Pyrolysis of petroleum-based synthetic polymers often produces volatiles which are similar to those originating from common accelerants. This presentation is intended to describe the role of mass spectrometry (MS) as a tool for the proper recognition of petroleum-based accelerants in complex matrixes.

ANALYTICAL METHODOLOGY

Figure 1 summarizes the major features of commonly accepted analytical methodology. Procedures for the determination of solid oxidizers and other inorganic accelerants require entirely different analytical approaches and will not be discussed here. The first step of the general analysis process involves the isolation of volatiles from the matrix, a step commonly referred to as sample preparation. The goal of this step is to secure an adequate amount of volatile material for subsequent characterization by gas chromatography (GC). Since the method calls for a qualitative, rather than a quantitative assessment, it is only necessary to collect a representative fraction of the volatiles present. The selection of the most appropriate sample preparation procedure depends on the expected level of volatiles and their anticipated volatility. Bertsch *et al.* (1990) compared the merits of direct headspace sampling to adsorbent-based enrichment methods, solvent extraction, and steam distillation and came to the following conclusions:

- Direct headspace sampling requires a fairly high concentration of volatiles. It is favored for low-boiling range mixtures.

- Enrichment of headspace vapors on adsorbents by either a static or dynamic process is the most sensitive of all methods.

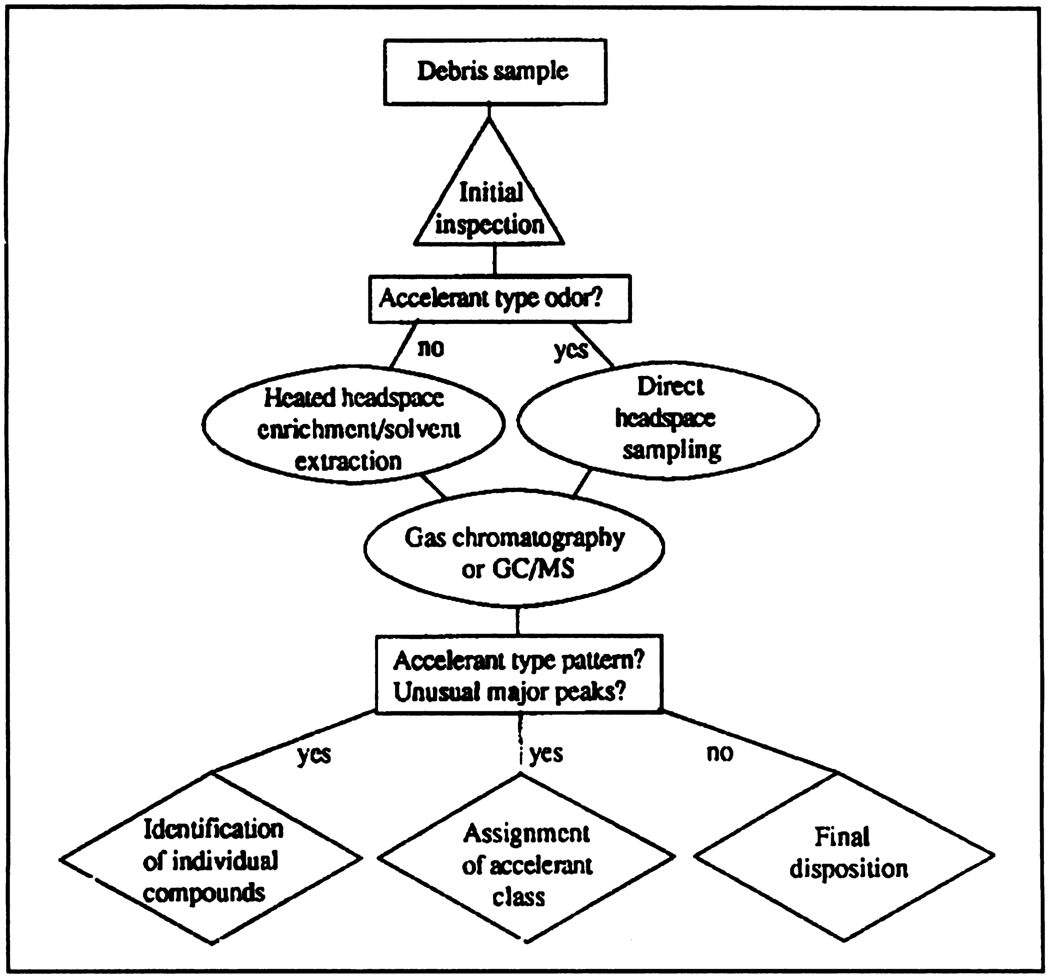

Figure 1. Simplified flow diagram of major steps in the overall process.

- ♦ Solvent extraction is the only technique which has the potential of good recovery for high-boiling range distillates. It also is afflicted with a significant degree of artifact formation.

- ♦ Distillation in any of its variations does not offer advantages over the methods summarized above.

In practice, many analysts use more than one sample preparation method. The human nose often serves as an initial screening device. Some chemists are quite successful in distinguishing the odor of accelerant-type volatiles from those emanating from the matrix, but the potential problems are obvious. Strong smells from the background can mask substances with low-odor thresholds and there are also health considerations. Few analysts recognize that odors from pyrolysis volatiles can be quite toxic (Hauser *et al.* 1994). Regardless of the method chosen, it is important that it is compatible with the next step which almost always involves a GC separation on a capillary column.

The stationary phases used in accelerant analysis are mostly conventional polysiloxane-based polymers. Depending on column quality and the characteristics of the sample under consideration, more or less complex chromatograms can be generated. The degree of separation which can be achieved largely depends on the efficiency of the column. Column selectivity is seldom used to enhance the separation because it is ineffective in dealing with the saturation of peaks on the space available in the chromatogram. Occasionally, samples are rerun on a polar column to effect a separation which is difficult to accomplish on a boiling-point type apolar stationary phase. Brettel *et al.* (1986) used dual columns in parallel to enhance the chromatographic separation. Jayatilaka and Poole (1994) demonstrated the usefulness of a multidimensional approach in the heartcutting mode, but this procedure is relatively complicated and time consuming. Packed columns have been substituted by capillary columns quite some time ago. It appears that many users originally refitted existing packed column instruments for use with wide bore capillary columns before finally switching to standard bore capillary columns (Bertsch and Holzer 1995).

Figure 2A shows chromatograms of a kerosene standard obtained on two different columns. The top chromatogram was produced on a 5 m x 0.53 mm i.d. wide bore column capable of generating approximately 10,000 theoretical plates. The lower chromatogram came from a standard 25 m x 0.21 mm i.d. column producing slightly in excess of 100,000 theoretical plates. There is obviously no problem in recognizing the general profile of kerosene, as represented by a unimodal distribution of the n-alkane series. On the other hand, important detail for trace components eluting between the n-alkanes is lost if the resolving power of the column is inadequate. This is shown in Figure 2B which is an enlargement of the C_{12} to C_{14} region of the chromatogram. One should keep in mind that this example which represents a pure standard is the best possible scenario. There is obviously a tradeoff between information lost by inadequate GC and other factors such as the time required for an analysis. GC on highly efficient capillary columns is now a routine matter. In most debris samples, accelerant-type compounds are usually present in sufficient quantity to produce usable chromatograms without optimization of sample introduction technology. GC appears to be the least demanding step of the overall analysis procedure.

Most analysts agree that chromatogram interpretation is the most critical and error-prone step in the overall process. The chromatographic pattern of the sample is visually compared to a series of accelerant standards obtained under similar conditions. Accelerants are commonly classified into five groups (Guidelines for Laboratories 1988). The classification scheme relies primarily on boiling-point range with little regard to chemical composition. Identification of an accelerant is based on the recognition of key components and requires that the chemist can distinguish between chromatographic patterns from interferences and those of several accelerant types which may have undergone modification as a result of exposure to fire. Changes in composition due to environmental factors are

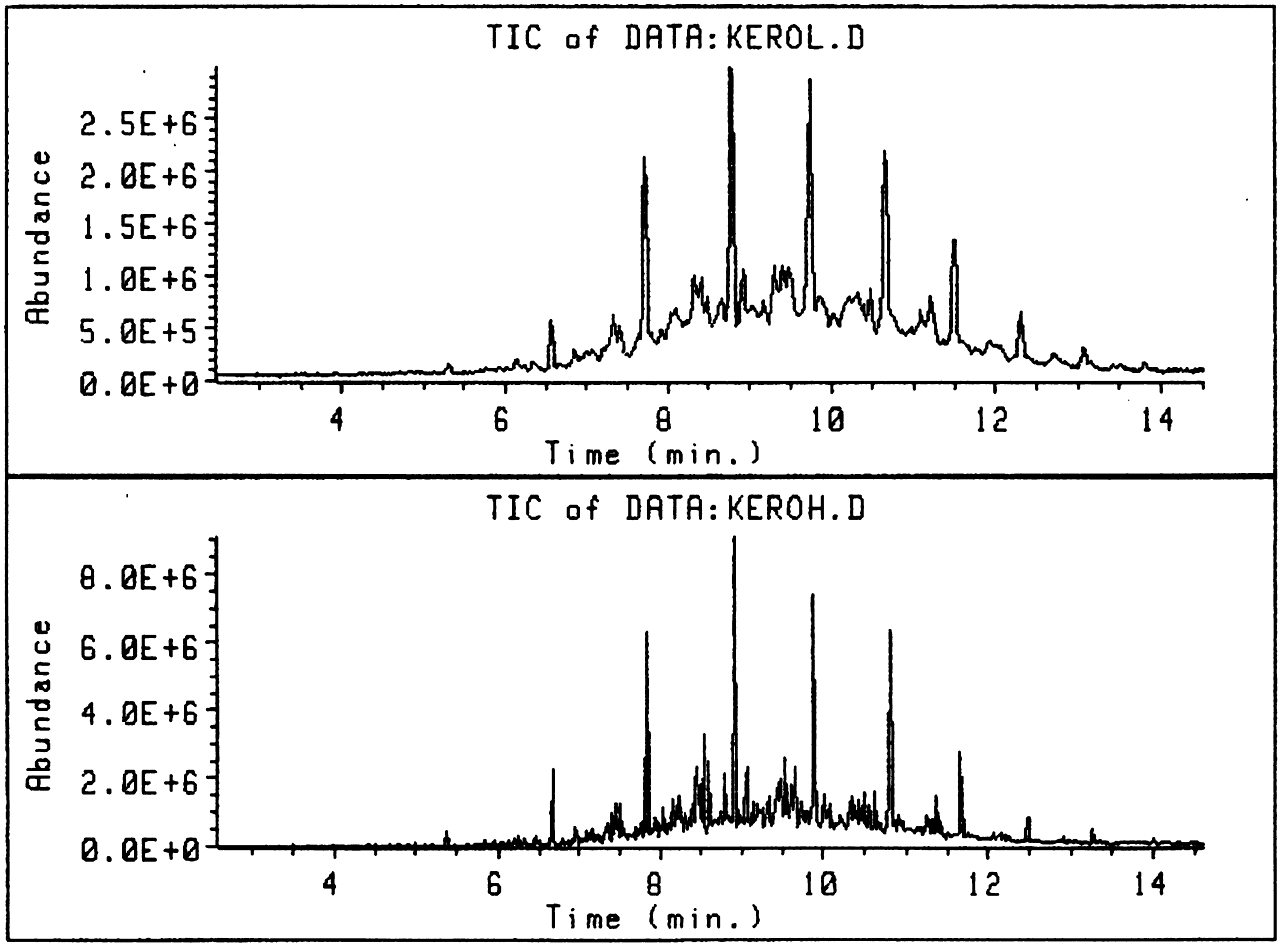

Figure 2A. Kerosene standard under low resolution (top) and high resolution (bottom). Column at top: 5 m x 0.53 mm, 2.56 µm methylpolysiloxane. Column at bottom: 25 m x 0.21 mm, 0.33 µm polymethysiloxane.

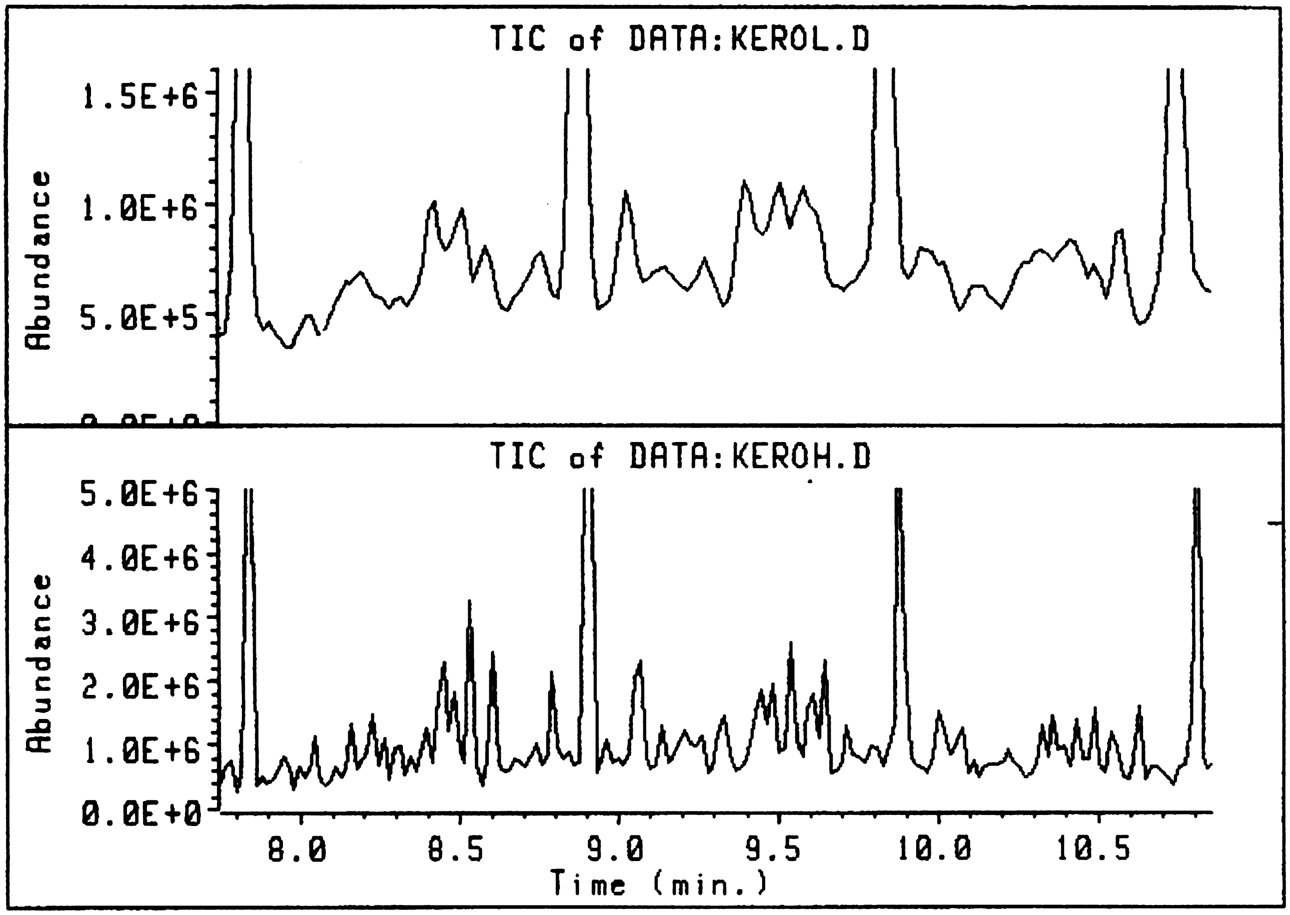

Figure 2B. Expansion of Figure 2A.

Table 1. Factors in Pattern Recognition By Visual Comparison of Chromatograms	
Factor	Example
Intrinsic Recognizability of Accelerant	Accelerants producing evenly-spaced peaks such as n-alkane homologs are easier to determine than accelerants with random patterns.
Ratio of Accelerant to Interferences	Complex chromatograms where interferences dominate are very difficult to interpret.
Chromatographic Resolution	Well-resolved groups of peaks, as produced by capillary columns are easier to recognize than broad peaks from low-efficiency systems.
Display Mode and Method of Comparison	Features to be compared should be of approximately the same intensity and displayed side by side or as overlay.
Experience of Analyst and Other Human Factors	Human factors are difficult to measure.

generally referred to as weathering. It is obvious that interferences often overshadow the traces of volatiles left after a fire. Methods for physical removal of interferences or for selective detection of the target compounds can greatly simplify this process which is often referred to as pattern recognition; both approaches are possible. The former can be based on the use of solid phase extraction cleanup methodology (Aldridge and Oates 1986) or acid stripping (Juhala 1979), but additional sample manipulation is necessary. The use of an accelerant-specific detector is a more attractive proposition. A device which specifically measures the potential of a fire debris sample or a sample extract to accelerate a fire is neither realistic nor technically feasible. MS in conjunction with GC is the next best solution. MS can be used to discriminate against interferences and extract accelerant-specific chromatographic profiles from a convoluted pattern.

DATA INTERPRETATION BY PATTERN RECOGNITION

In principle, pattern recognition can be carried out by a human or by a properly programmed computer. Typically, the analyst visually compares chromatograms and makes a subjective determination about a possible match between the sample chromatogram and a chromatogram from a library of accelerant standards. This process depends on many variables which are not always easy to define. Table 1 summarizes the most important factors. There is obviously a subtle interplay between many variables. Each of the principal steps presented in Figure 1 needs to work at least marginally to obtain a valid result (*i.e.*, low recovery in the sample preparation step may be compensated for by a highly sensitive GC detector). The recognition of an accelerant pattern in a debris sample has similar constraints. Accelerants which are dominated by a series of homologs are generally more easily recognized than those producing irregularly spaced peaks. Samples containing MPD, kerosene, and fuel oil are distinctive even if 90% of the original accelerant has been lost.

Adequate chromatographic resolution is another factor which is important in recognizing an accelerant pattern. The most crucial element is, however, the ratio of interferences from the background to the accelerant. This is particularly critical if the accelerant in the debris sample is characterized by a pattern of randomly spaced peaks. A simple example may illustrate this condition and point out avenues that can be taken to remedy this situation. Figures 3 and 4 show chromatograms of 80% evaporated gasoline, a matrix profile, and a simulated arson sample consisting of the spiked matrix under conditions of low and high chromatographic resolution. The columns used were the same as in Figure 2. The level of the gasoline spike has been chosen to make it relatively difficult for the observer to recognize differences between the matrix and the simulated arson sample. This particular sample shows that an improvement in chromatographic resolution may not be sufficient to assign an inherently difficult accelerant profile with a sufficient degree of confidence. Removal of some interferences by mass spectral filtering should improve the situation. Figure 5A shows the C_2 alkylbenzene, C_3 alkylbenzene, and methylnaphthalene regions for the matrix chromatogram in 4A in greater detail. As expected, the total ion chromatogram shows a great deal of interference from the background. It also can be seen that the selected ion chromatograms produce a few peaks in the diagnostically important ranges. Figure 5B compares the extracted ion chromatograms between the matrix, spiked matrix, and corresponding accelerant standard for the same ions. The matrix clearly produces some of the target compounds, but the peak ratios are severely distorted. On the other hand, there is a good match between the selected ion chromatograms of the spiked matrix and the standard.

A significant improvement in pattern recognizability has been achieved in comparison to the total ion profiles for the matrix and spiked sample in Figure 4. It should be noted that most samples encountered in practice are either dominated by an accelerant-type profile or do not appear to contain diagnostic peaks for any of the typical accelerants. It is nevertheless interesting to examine the relationship of the variable chromatographic resolution, accelerant type, accelerant concentration, and mass spectral selectivity.

A factor often overlooked is how the method of chromatogram presentation affects the outcome when the analyst carries out a visual comparison. Availability of modern equipment for chromatogram display may influence the recognition of an accelerant profile and may, thus, have a direct bearing on the outcome of the analysis. The human brain is very effective in processing short-term information. A person looking at two chromatograms displayed side by side can detect even minute differences and/or similarities. If this process is separated in space or time, the expected outcome is not nearly as favorable. Modern data systems facilitate scaling and adjustment of peak size while allowing direct overlay or side-by-side presentation at the same time. MS can diminish some of the interference problems and lower the hurdles, but it cannot introduce new elements which eliminate the fundamental challenge of recognizing a weathered accelerant in a convoluted chromatogram.

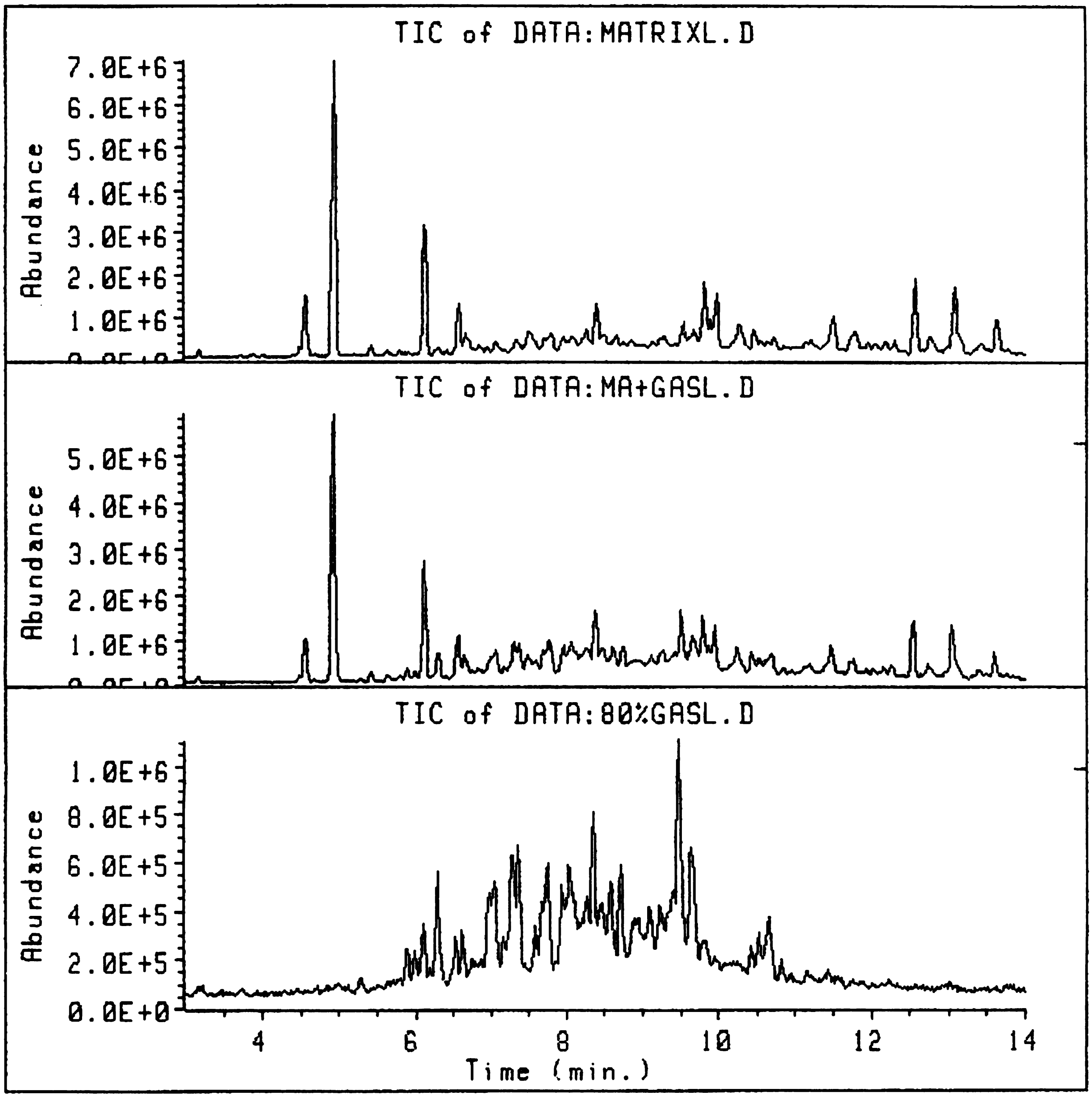

Figure 3. Chromatograms (total ion current plots) of a fire debris matrix consisting of carpet/carpet padding (top), a simulated arson sample produced by spiking the matrix with 80% evaporated gasoline (middle), and a standard of 80% evaporated gasoline (bottom). Low resolution column.

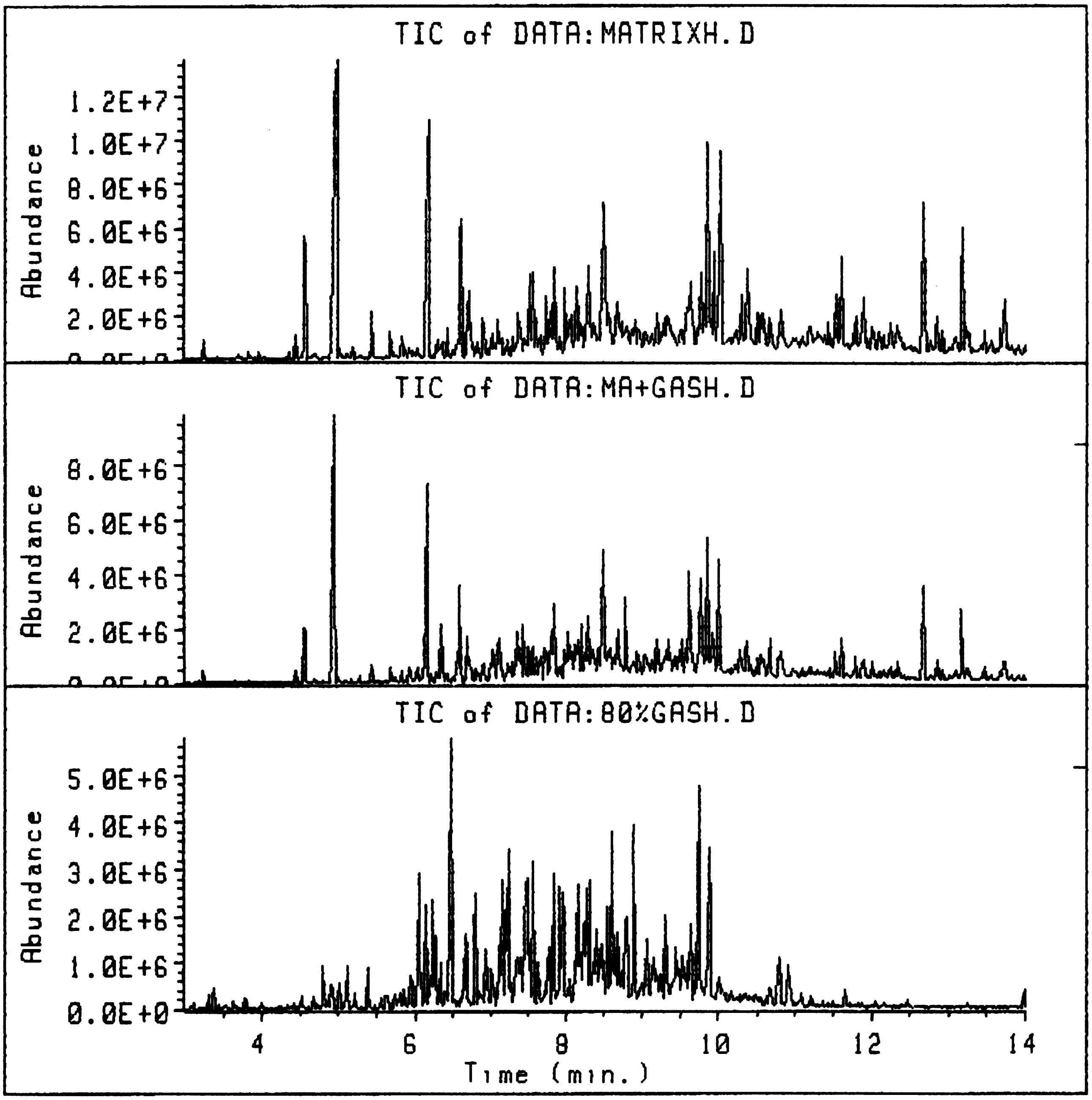

Figure 4. Chromatograms (total ion current plots) of samples as in Figure 3. Matrix (top), simulated arson sample (middle), and accelerant standard (bottom). High resolution column.

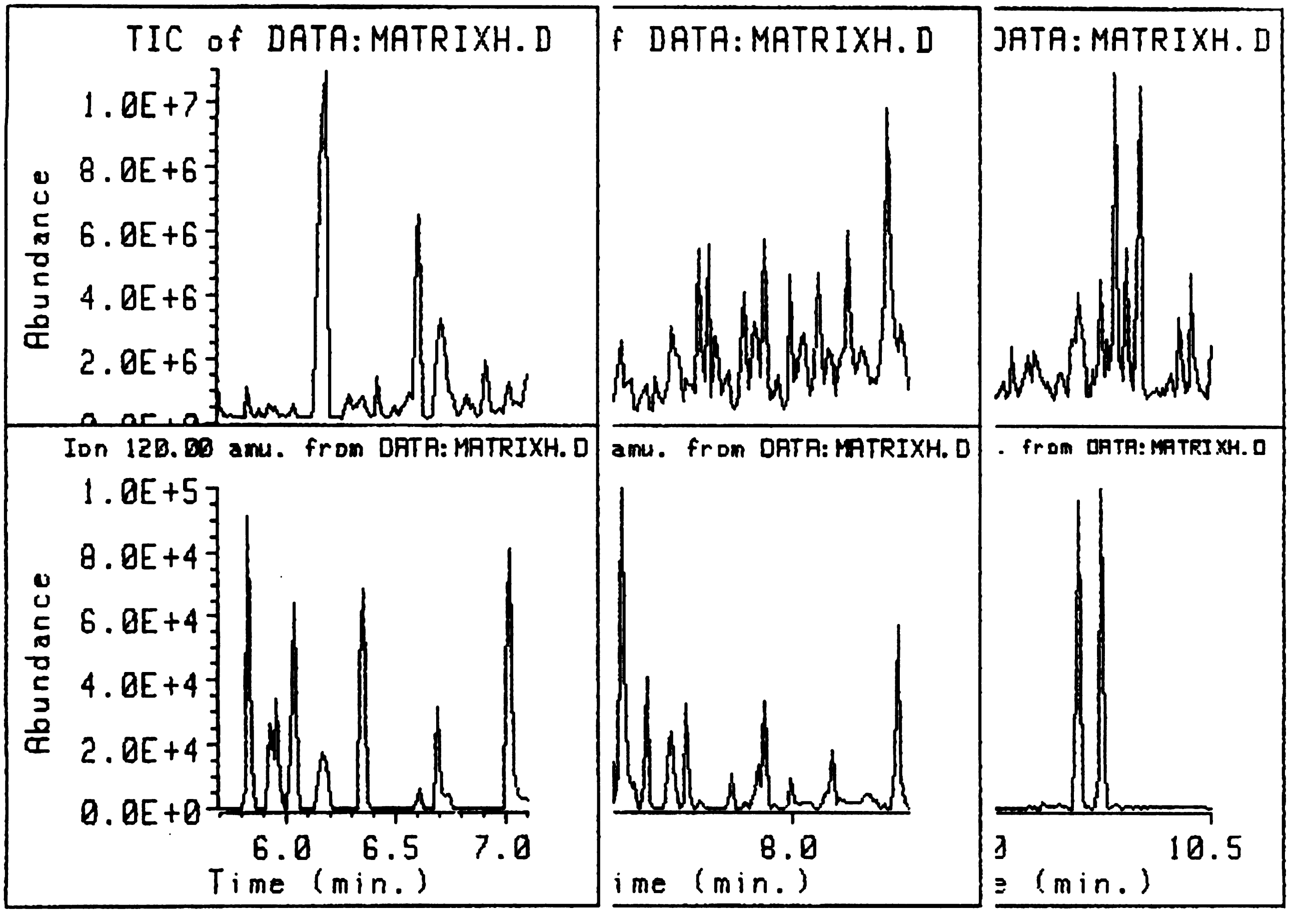

Figure 5A. Total ion chromatogram and C2 alkylbenzene, C3 alkylbenzene, and methylnaphthalene diagnostic regions for the matrix sample shown in Figure 4 (top).

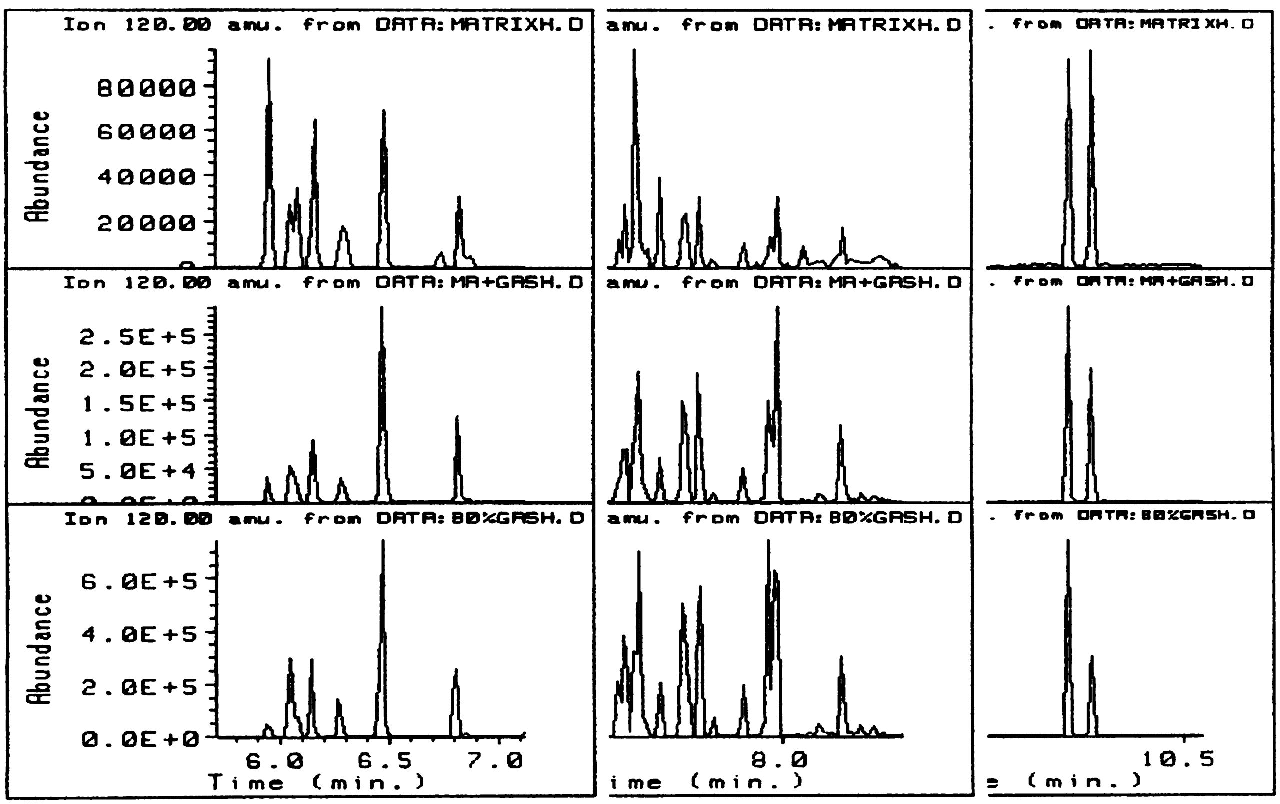

Figure 5B. Extracted ion chromatograms, as in Figure 5A, for the matrix spiked matrix and accelerant standard from Figure 4.

It is an important tool to diminish interferences, but it cannot help in a situation where the matrix produces compounds which are identical to those indicative of an accelerant as has been demonstrated in Figure 5. There may also be an element of operator bias which has to be dealt with. A sample which has a strong accelerant-type odor will probably be treated differently from one which does not produce a noticeable odor. Instrument-based expert systems can remove much of the human factor, but add to the complexity of the analysis system. An expert system is discussed at the end of this presentation.

THE ROLE OF MASS SPECTROMETRY

MS is a device capable of generating common ions for substance classes which share similar structural features. To be useful as an accelerant-specific device, ions produced by accelerants and background should be as dissimilar as possible. Furthermore, there should be distinguishing features between the ions generated from different accelerants; both requirements are met, to some degree. Petroleum-based accelerants generate a relatively small number of diagnostically useful ions. Table 2 is an adaptation of the accelerant classification scheme originally proposed by scientists at the laboratories of Alcohol, Tobacco and Firearms and the Center for Fire Research of the former National Bureau of Standards. It arose in 1982 and was formally adopted in 1988 by the Forensic Science and Engineering Committee of the International Association of Arson Investigators. Variations of the same scheme which include mass spectral information have been proposed by Bertsch and Holzer (1988), Novicki (1990), and more recently by Holzer *et al.* (1992). Keto and Wineman (1991) suggested an expanded list which includes the diagnostic ions for alkylcyclohexanes, alkylindanes, and decalin. A rationale for the selection of diagnostic ions has been presented by Smith (1989) in his excellent review.

The level of noise reduction is not only related to the uniqueness of the selected ions to describe salient features of the accelerant-type compounds, but also to the ions produced by common background pyrolysates. Carpet and carpet padding contain composite materials which are held together by adhesives. Many synthetic polymers including polyethylene, polyimide, PVC, and nylon may be used in the manufacture of carpets. Pyrolysis of these types of materials and a host of other widely available polymers, commonly referred to as plastics, is likely to produce a variety of hydrocarbon fragments which have a potential of competing with accelerant-type compounds (Bertsch 1994; Clodfelter *et al.* 1971; Keto 1994; Smith 1982). Plastics are used widely in building and construction, constituting approximately 7% of the cost of materials (Reisch 1994). Carpet and carpet padding are, unfortunately, the materials of choice from the fire investigator's point of view. Approximately two-thirds of all fire debris samples submitted for analysis contain carpet and carpet padding (Bertsch and Zhang 1990). The problem is, thus, to find a way to discriminate against these interferences.

The distribution of volatiles generated by pyrolysis depends on many variables which are difficult to assess (Hawley-Fedder *et al.* 1987). In many carpets, styrene and its alkyl homologs are the major thermal breakdown products (Bertsch *et al.* 1993; Smith 1982). Chromatograms containing large amounts of styrene produce some alkylbenzenes, naphthalene, and similar fragments which are also the diagnostic components for gasoline. The distribution is, however, quite different from petroleum-based accelerants. It is astonishing that petroleum-based accelerants of widely differing boiling ranges and type do not only share some of the same aromatic components, but the ratio of the isomers within a group is relatively constant. The pattern of alkylbenzenes in gasoline and in many distillates which are dominated by n-alkanes is quite similar, even though their general chromatographic profiles are very different. The isomer distributions remain intact, even after exposure to a fire. On the other hand, profiles of alkylbenzenes originating from pyrolysis of synthetic polymers show distortions. Usually a single isomer dominates the pattern.

AUTOMATION IN PRESENTATION

After completion of analysis, including a visual comparison of chromatograms, a determination must be made if an accelerant is present. This is often a very difficult decision because the only acceptable answers are "yes" or "no." Results such as "inconclusive" or "uncertain" are not meaningful. It is difficult to describe a match between chromatograms in quantitative terms. A perfect match can obviously not be achieved even for identical samples because there are always some experimental variations. In practice, the sample chromatogram from the sample is compared to a library of standards which may have been collected quite some time ago. Extensive libraries may contain dozens of accelerants and it is impractical to regenerate chromatograms to account for retention time changes due to column aging. Fortunately, the human observer can easily compensate for shifts in retention time by mentally transposing the patterns. Accelerant profiles which

Table 2. Accelerant Classification System				
Class Name and Number	Approximate Range (n-alkane carbon numbers)	Examples of Products	Dominant Component Classes	m/z of Mass Fragmental Ions
1 - Light Petroleum Distillates (LPD)	C_4 - C_8	Petroleum ethers, pocket lighter fuels, Skelly solvents, VM&P naphtha.	Alkanes (branched, low MW)	43, 57, 71 ...
2 - Gasolines	C_4 - C_{12}	All brands & grades of automotive gasoline including gasohol, some camping fuels.	Alkanes (branched, low MW) Alkylbenzenes (low, MW) Naphthalene (and low MW alkylderivatives)	43, 57, 71 ... 91, 106, 120 ... 128, 142, 156 ...
3 - Medium Petroleum Distillates (MPD)	C_8 - C_{12}	Paint thinners, mineral spirits, some charcoal starters, "dry-cleaning" solvents, some torch fuels.	Alkanes (normal, low MW) Alkylbenzenes (low MW)	43, 57, 71 ... 91, 106, 120 ...
4 - Kerosene	C_9 - C_{16}	No. 1 Fuel oil, Jet-A (aviation) fuel, some insect sprays, charcoal starters, some torch fuels.	Alkanes (normal, medium MW) Alkylbenzenes (low MW) Naphthalene (and low MW alkylderivatives)	43, 57, 71 ... 91, 106, 120 ... 128, 142 ...
5 - Heavy Petroleum Distillates (HPD)	C_{10} - C_{23}	No. 2 Fuel oil, diesel fuel.	Alkanes (normal, high MW) Alkylbenzenes (low to medium MW) Naphthalenes (and similar alkylderivatives)	43, 57, 71 ... 120, 134, 148 ... 128, 142, 156 ...

have been simplified by precolumn cleanup or which have gone through mass spectral processing are obviously more easily recognized. To increase confidence, as many peaks as possible should be matched between the sample and corresponding accelerant standard.

Data systems from mass spectrometers produce copious amounts of data in the form of extracted ion chromatograms which need to be compared to the corresponding data from accelerant standards. In practice, some compromise has to be found between data processing time and, more importantly, the volume of data displayed. Computers are very effective in providing tabular data, but the analyst should insist on a visual presentation in the form of chromatograms and not only rely on numbers.

The extraction of ion profiles is a relatively straightforward process which can be controlled from the softkeys of the GC/MS software. To be effective, profiles of several ions need to be compared simultaneously for the sample and at least some of the major accelerant classes. There are no fundamental differences between pattern recognition of general response chromatograms and extracted ion profiles. The observer needs to be able to view some patterns, such as an n-alkane profile over a wide range whereas a narrow retention time window may be more suitable for a specific isomer group. It is logical to automate such a process by instructing the computer to go through a postrun routine where appropriate selection ion chromatograms are displayed in a user-friendly format. An example of such an automated display program has been presented by Bertsch *et al.* (1988).

Figure 6 shows a printout of a past run report for the simulated arson sample displayed in Figure 3. This particular report has been produced on a Hewlett Packard benchtop instrument operating in a PASCAL environment, but it should also be adaptable to GC/MS instrumentation from other manufacturers. Details on the algorithm have been reported elsewhere (Bertsch and Holzer 1995). The one-page format was chosen as a compromise between the minimum information the analyst needs to make a decision and computer processing time. The program is fairly lengthy and requires approximately 5 minutes between the end of data collection and the end of the print routine. Users having access to high-speed computers and fast printers can easily expand the report or shorten data processing time.

Figure 7 shows a flow diagram of the process. It is controlled by a user-written program commonly referred to as a macro. A macro consists of a series of commands such as get file X, extract m/z 57, integrate the extracted ion chromatogram, draw the ion chromatogram in a specified range to the screen, and print. The computer accepts the command from the program rather than the keyboard. The use of variables and conditional statements such as "if/then" and "while" loops increases system flexibility. In the diagnostic program presented in Figure 6, a macro directs both data collection and data processing. Page 1 (not shown) of the diagnostic report displays a full-size total ion chromatogram of the sample and a chromatogram of a previously acquired blank run to ensure that the system produces no artifacts. The use of optional background checks is important because of the ever present danger of cross-contamination in a laboratory. It is one small but important step toward a quality assurance program which should be part of every forensic laboratory (Brunelle *et al.* 1982). One needs to keep in mind that some fire debris samples may contain very large amounts of accelerants and the transfer of even a tiny fraction between samples can result in a false positive.

The diagnostic report in Figure 6 displays a large amount of information with some built-in redundancy. Some of the selected ion chromatograms such as m/z 69 and m/z 103 which are indicative for alkanes and styrenes, respectively, have been chosen to indicate potential artifacts. Some parts of the chromatogram are expanded for better viewing. Chromatographic conditions have been optimized for elution of all compounds of diagnostic interest even though the display does not show the entire chromatogram. Alkanes in HPD range up to about C24 and the analyst can pull up the original file from the computer to verify the presence of the high bp range compounds not shown on the diagnostic report. The strength of the format is the side-by-side presentation of extracted ion chromatograms from the sample and typical accelerants. Direct comparison is an invaluable help for the recognition of complex profiles consisting of irregularly spaced components. The human observer can easily remember the relative position and intensity of a small number of features such as the "xylene group" which contains only three peaks. The situation becomes more difficult with the higher homologs of alkylbenzenes which are important indicators of partially evaporated gasoline. This is particularly true when the relative peak height of isomers in each group is used as one of the criteria in identification. It is useful to also consider absolute peak height response.

The diagnostic report in Figure 6 includes an abundance of information which has been partially omitted in Figure 4, for simplification. While quantitation is not an important facet of accelerant analysis, it is necessary that the analyst can determine

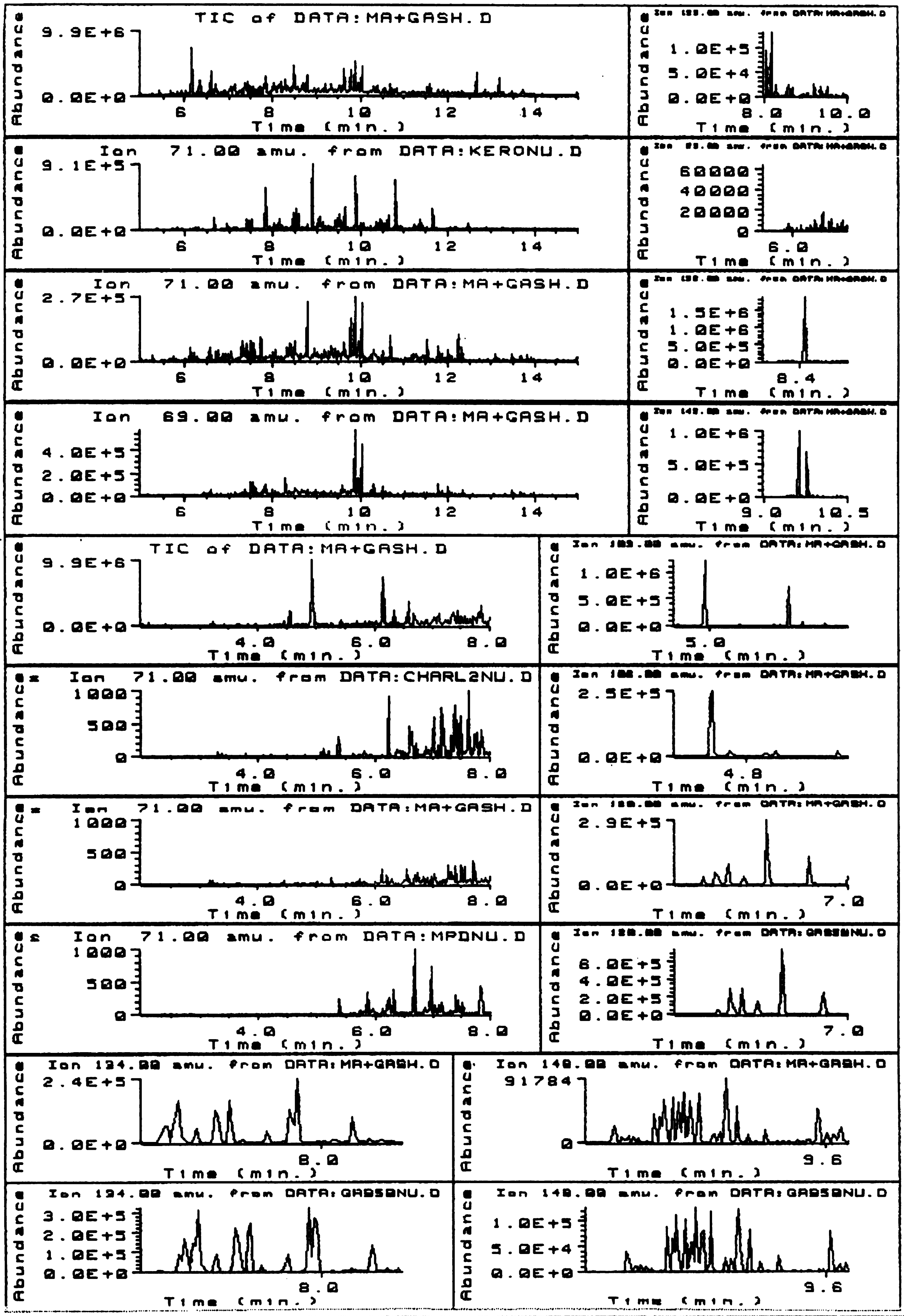

Figure 6. Diagnostic report for the simulated arson sample in Figure 4 (middle).

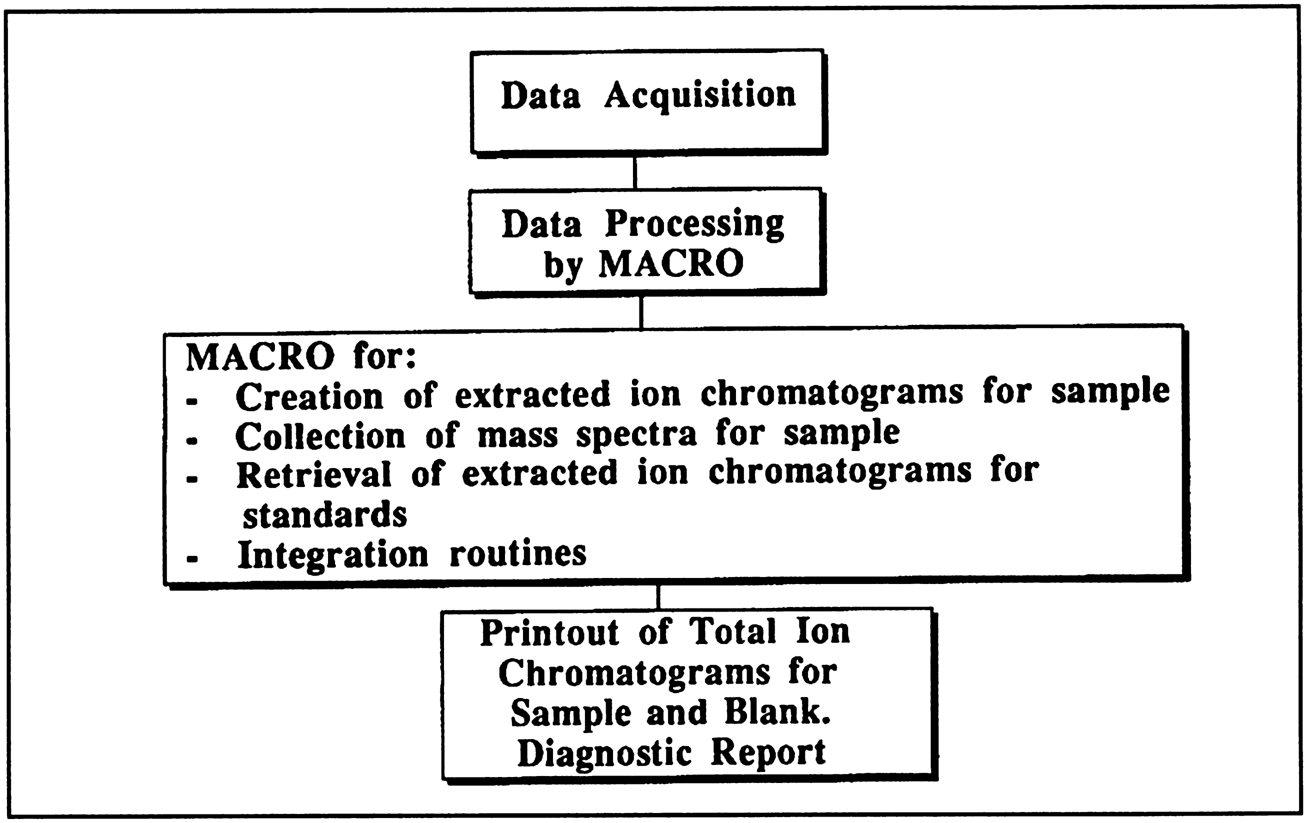

Figure 7. Flow diagram for a diagnostic report.

if the sample response exceeds some threshold level. Adsorptive materials such as carpet and carpet padding may produce a weak response for gasoline-type components. The reader needs to keep in mind that ambient air in urban centers contains traces of gasoline-type compounds which can adsorb on retentive materials. A highly sensitive system can, therefore, produce a low-level "false positive."

The accelerants chosen for the diagnostic report in Figure 6 represent all major types of accelerants including turpentine and an isoparaffin-type distillate found in some charcoal lighter fluids. The report which consists of 14 boxes for the sample and 6 boxes for comparison standards may appear to be excessively complex. In practice, it is seldom necessary to study the entire report. Most samples either fall into the negative category or produce strong responses in one or more boxes indicating the unequivocal presence of an accelerant. Cases that fall in between require additional study which may include interpretation of individual mass spectra. Large peaks in the early part of the chromatogram are also of particular interest. Single compounds such as toluene or simple mixtures, including varnishes and industrial solvents, can easily be identified by their mass spectra.

AN EXPERT SYSTEM

Computer-generated displays of extracted ion chromatograms facilitate the recognition of accelerants, but the analyst still has to reach a decision based on subjective criteria. Pattern recognition can also be carried out under the control of a computer with little or no human intervention. It is used widely for applications as different as weather forecasting and DNA analysis. Commercial software packages are available which can operate on GC data sets, but applications to fire debris analysis have not appeared to date. Considering the complexity of the task, it is unlikely that general data analysis programs will ever be applied to accelerant analysis. User-written expert systems provide a more promising avenue toward automated analysis. A few GC/MS-based expert systems have been described in the literature. Novicki (1990) recently described the use of macro programming for automated data analysis. His program leans on the use of n-alkane retention indices and a user library containing retention data for common accelerant compounds. Compounds meeting established criteria are verified by a mass spectral library search and a total ion chromatogram; a list of identified peaks and several selected ion chromatograms are printed out.

The ATF group (Keto 1994; Keto and Wineman 1991; Wineman and Keto 1994) uses both extracted ion chromatograms and a process leading to target compound chromatograms. The latter are essentially reconstructed chromatograms in the form of stick plots which indicate the retention time and relative amount of each accelerant-type compound identified. The basic difference is that only specified substances which have been identified in accelerants are considered in the target compound chromatograms. Identification of the target compounds relies on retention time and the ratio of at least two different fragments. Visual pattern recognition is used to confirm the fit between the profiles of the sample and corresponding accelerant standard. The final output is a histogram-type presentation which shows profiles of diagnostic ions.

The approach originally developed by Bertsch *et al.* (1989) for the analysis of petroleum-type products in the environment uses similar criteria. The program starts with data acquisition and ends with a coded table. The table is the final result of a peak search routine which describes the composition of the sample in terms of n-alkanes, branched alkanes, C_2 to C_5 alkylbenzenes, naphthalene, and methylnaphthalenes. Individual compounds identified by the system and some of their ratios are listed. The program has evolved over several years and is based on data collected from petroleum distillates, matrix pyrolysates, and several hundred fire debris samples (Bertsch and Zhang 1990; Holzer *et al.* 1992). The system can automatically print out total ion chromatograms of the sample and its closest match from the accelerant library. The program also has an option to print out selected ion chromatograms and some diagnostic mass spectra from corresponding peaks in the sample and accelerant standard. It consists of several subroutines which are linked to each other. The algorithm moves back and forth between the domains of GC and MS. It starts by searching for the presence of key compounds in the sample. Several criteria must be met simultaneously for substance confirmation.

The program uses retention times, mass spectral fragmentation patterns, and molecular ions. The peak identification subroutine is the most important part of the program. It establishes the presence of diagnostic components in the sample. It also determines if a required substance is absent. Additional peaks are common and are not cause for alarm. Missing peaks are much more critical and are, therefore, treated differently. The program tries to identify approximately 40 different substances. It starts with the determination of ten n-alkanes. Because of their unique mass spectral characteristics, the retention time windows can be chosen within wide limits. In practice, fewer peaks have to be examined if the window is narrowed, saving computer processing time. The program uses the retention times of previously injected n-alkanes to calculate linear retention indices for the 40 diagnostic components. Modest shifts in retention time can be accommodated because the program recalculates the retention indices of all target compounds after it identifies the necessary n-alkanes. The relative independence of retention indices from experimental variables and as column temperature and flow rate allows the selection of relatively narrow windows for the evaluation of specific components in isomer groups. This is necessary for alkylbenzenes which do not produce compound-specific mass spectra. All peaks in the defined window are integrated and the mass spectral criteria of peaks above a preset threshold level are examined. For alkanes, ions with m/z values of 57, 71, and 85 must be present. The program searches for the most intense ion in a window of the fragment mass within ±5 amu. It also looks for the molecular ion, but accepts a compound as an n-alkane if the mass spectral criteria intensity ratios of the three fragments are met.

Branched alkanes require individual criteria because relative ion intensities depend on branching. The program searches for seven branched alkanes between C_9 and C_{15} and also for pristane and phytane which are diagnostic components in HPD. The treatment of alkylbenzenes is somewhat different. The distribution of structural isomers is relatively constant and peak ratio limits within each group can be used as additional criteria. A group is only recognized if all selected compounds within the group meet all retention time, mass spectral, and peak-size ratio criteria. For example, the ratio of o-xylene to the unresolved m + p-xylene must be smaller than 0.6 for acceptance of this group. Ethylbenzene is not used because it can be an artifact from polymer decomposition. The other alkylbenzene isomer groups are examined in a similar manner. The number of criteria chosen to identify a specific group depends on complexity and abundance. Six peaks are ratioed in the C_4 alkylbenzene group which is the most important diagnostic region for weathered gasoline.

Identification of individual components and isomer groups is a necessary, but insufficient prerequisite for the determination of a specific accelerant and its placement into the classification scheme. It is necessary to calculate the relative contribution of each isomer group in the chromatogram and use this information to narrow down the choice of an accelerant. For example, a weak sample of slightly weathered gasoline produces a

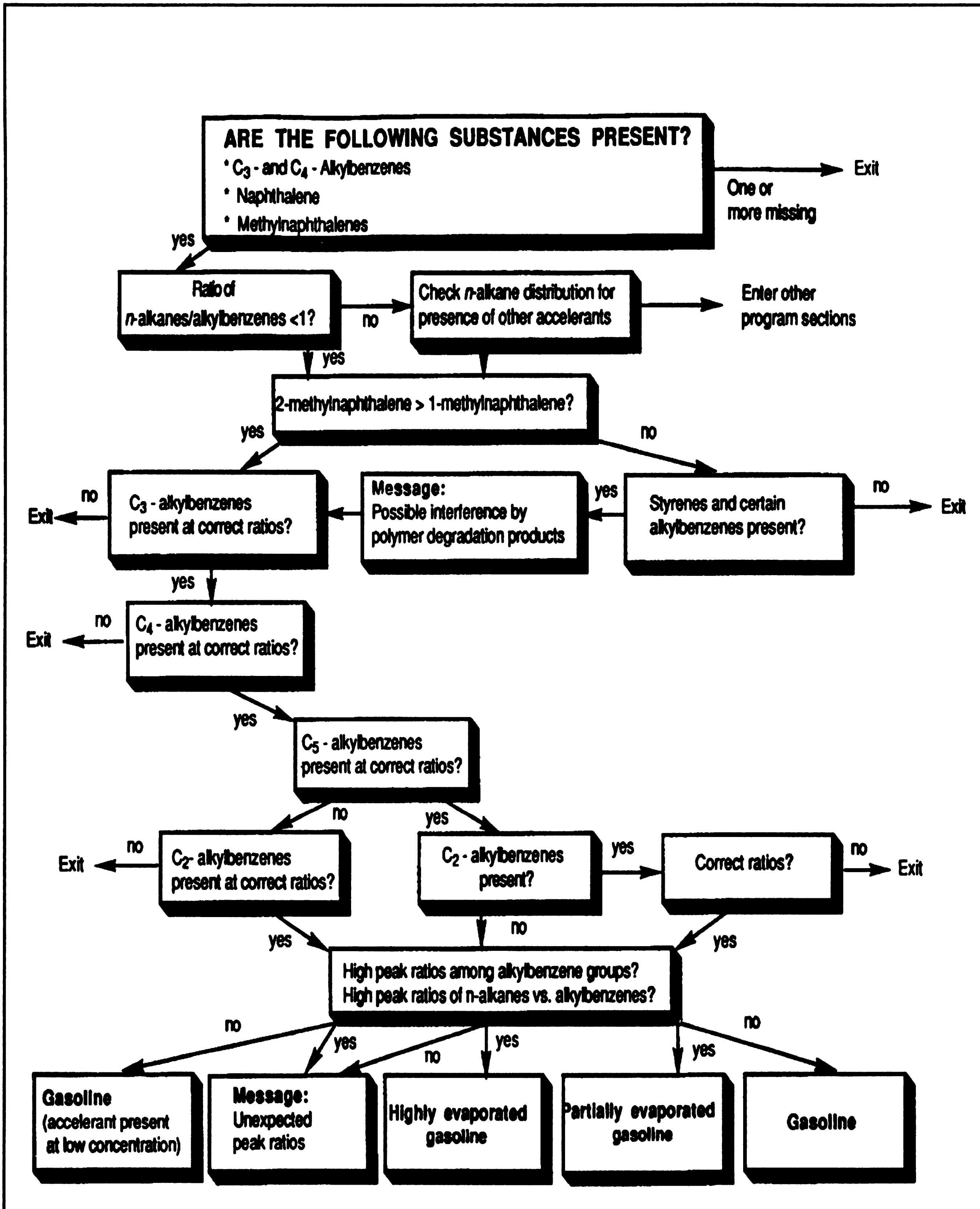

Figure 8. Flow diagram of the principal steps in the automated evaluation program for the identification of evaporated gasoline.

response for C_2 and C_3 alkylbenzenes which are also present in kerosene. A decision needs to be made which of the two accelerants is present.

Figure 8 shows how the program deals with this issue. The recognition of evaporated gasoline, as shown in Figures 3 and 4 is demonstrated. The program looks for n-alkanes and determines the boiling-point distribution by arranging the n-alkanes in order of decreasing relative amounts. The ratio of n-alkanes to alkylbenzenes is then calculated and, based on the outcome, the program moves into the appropriate loop for MPD, kerosene, HPD, or gasoline. The program verifies each group and displays a message if unusually large amounts of styrenes are present. Intensity ratios between different groups of alkylbenzene isomers are also calculated to distinguish between the various evaporation stages in gasoline. If the criteria are met, a tabular report is printed and the profiles of the sample and its closest accelerant standard are plotted side by side. The reader can find additional details in a monograph (Bertsch *et al.* 1993).

The expert system discussed works well for samples which are not dominated by interferences and which contain a reasonable level of accelerant. Unfortunately, this is not the situation where the analyst needs most help. It is clear that this system as well as any other expert system eventually fails as the ratio of accelerant to interference is gradually reduced. The system requires a significant level of maintenance and is not suitable for routine applications unless the analyst is fully trained. It does represent a first step toward full automation, but cannot replace the analyst. The human observer must play a central role and always have the last word.

OUTLOOK

Changes in the use of new technology often come slow. The introduction of routine GC/MS to forensic laboratories for specific use in arson-type investigations is still some distance away. Advances in automation and, more importantly, the competitive pressure of market forces to offer low-cost GC/MS instruments will eventually change the landscape in a fashion similar to the gradual replacement of packed by capillary-column technology. Miniaturization will be another boom making it eventually possible to carry GC/MS instrumentation to the fire scene. Membrane introduction MS is already being used for similar purposes (Kotiaho *et al.* 1991).

Several portable mass spectrometers are already on the market (Newman 1991). The use of MS/MS to add selectivity has not even been fully explored yet. Introduction of these technologies will undoubtedly help the analyst to find accelerants at lower and lower levels. The problems remaining in accelerant analysis are more of a fundamental and less of a technical nature. Petroleum-based hydrocarbons are ubiquitous in the environment. Its distillates are used in such a large variety of human activities that it is very difficult to determine if the presence of an accelerant in a fire debris sample stems from a willful act of arson or is simply a consequence of manufacture or environmental contamination. Constant vigilance of all parties involved in the investigation of arson is necessary.

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Interpretation of Problem Chromatograms

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The two major areas which I will discuss, as they affect the interpretation of problem chromatograms, are sources of problems and the interpretation factors themselves. Within sources of problems, key factors concerning separation techniques and instrumentation will be covered. Within the interpretation of chromatograms, the production, parameters, and actual comparison of chromatograms will be discussed with actual examples.

We occasionally encounter problem chromatograms and face difficulty in their interpretation, not due so much to the accelerant or debris itself, but due to the fact that we have made it difficult for ourselves. Sometimes this can happen by using the improper recovery technique on the sample or by performing the correct recovery technique improperly while trying to isolate the accelerant from the debris. One should always consider what inherent limitations a recovery technique possesses and how that may affect the resulting chromatograms. Then one must consider, if needed, what substituted or additional techniques will overcome those limitations.

With respect to recovery techniques, I will address problems associated with headspace sampling, activated charcoal adsorption, and solvent extraction. Headspace sampling, whether conducted at ambient or heated temperatures, may not always produce a total representation of the compounds of the accelerant, but will generally accent those components having the lower-boiling points. Thus, one may encounter problems such as those seen in chromatograms having many large peaks in the first few minutes, followed by a quick drop-off of peak intensity and very little indication of medium or heavy-boiling-point range compounds. A clearer representation of the accelerant's compounds may then be achieved by either briefly evaporating away the lighter compounds and/or conducting a solvent extraction on a portion of the debris.

With activated charcoal adsorption, a couple of problems can be evident in the resulting chromatograms. When evacuating the air in a container of debris through a tube packed with activated charcoal (commonly referred to as the dynamic method), overheating the sample may cause the tube to heat up and a thermal desorption of the light boilers to take place. When using the charcoal strips (commonly referred to as the passive diffusion method), notable displacement of volatile compounds can occur when: the duration of the adsorption is excessive; the temperature at which the sample is heated during adsorption is too high; or the size of the charcoal (surface area) is too low relative to the accelerant concentration.

In addition, when adding a solvent to desorb an accelerant from the charcoal, the least amount that can be used would be best. For the passive diffusion method, this is typically 0.1 - 0.2 mL of solvent for a charcoal strip measuring 5 mm x 15 mm. When extracting granular activated charcoal within a tube for the dynamic method, one would want to eventually retrieve about 0.1 - 0.2 mL of the solvent also, or a sufficient quantity for an auto sampler vial. If too much solvent is used, then the concentration of the accelerant may be low and subsequent evaporation of the extract for further concentration may cause a loss of the light boilers in the resulting chromatogram.

Subjecting the debris sample or a portion of the debris sample to direct solvent extraction can be overkill and should be used as a last resort in most instances. Solvent extractions can be very effective in dissolving accelerant residue, but can also be just as effective in dissolving other materials within the debris that will interfere or even mask compounds of interest from the accelerant on the chromatograms. At other times, the quantity of solvent used can be so large that evaporation will be required for concentration of the accelerant. Many times this

process has resulted in the loss of light and even medium-range boilers.

INSTRUMENTATION

Another factor that can contribute to the ease or difficulty in interpreting chromatograms from fire debris samples may not be caused by the analyst, but can certainly be detected and eliminated by the analyst right from the start. This factor is the condition of the instrumentation.

Just as a pilot examines a check list of settings and conditions before operating an airplane, it would be wise to learn from the benefits of such a practice. Perhaps we can eliminate or, at the very least, minimize problems that may arise during the instrumental analysis using the gas chromatograph. A number of parameters to check which could reduce problems and provide consistency would include: injector/detector temperatures; split ratio; carrier gas velocity/head pressure; temperature program; attenuation; and column condition. These parameters can often be checked by the appropriate use of blanks and standards as addressed in ASTM E-1387. One should also be sure to use a clean syringe and a consistent technique for injections.

INTERPRETATION

Chromatogram Production

In addition to performing a proper recovery technique on a sample and ensuring that the gas chromatograph is functioning properly, one can further remove difficulties from the process of interpreting chromatograms by following a few simple guidelines.

The point of injection, the start of the gas chromatograph run, or a solvent peak with a consistent retention time should be clearly indicated on the chromatogram. The major (most intense) peaks of the chromatogram (excluding solvent peaks) should be "on scale." This means that their height should be between 3/4 and full scale. Try to obtain a chromatogram with as level a baseline as possible. In order to add significance to the similarities of compounds depicted in the sample chromatogram with those in the known accelerant chromatograms, it is necessary to enhance and correlate well-resolved minor peaks that appear between the major peaks.

Chromatogram Parameters

It is also important that the x-axis (time) of the samples and known chromatograms be of identical scales for comparison and interpretation purposes. Whether time, carbon numbers, or boiling points are used does not matter as much as making sure the scales are identical for chromatograms of samples and standards.

To make the interpretation and comparison easier, try to identify what the sample chromatogram is not or could not depict. If the sample chromatogram only contains peaks in the C_{12} to C_{18} range, with no other peaks appearing prior to those, then it would be unnecessary to search for a light petroleum distillate within the chromatogram. The classification system of accelerants as listed in ASTM E-1387 is an excellent guide to follow in order to evaluate and compare the chromatographic profiles of compounds from samples to those of known accelerants.

Chromatogram Comparison

To begin a comparison between chromatograms from samples with those of known accelerants, it is best to work from a fixed starting point such as an injection point or solvent peak. Once again, the scales must also be identical. After the boiling-point range (light, medium, heavy) is initially established through the range of the major peaks, the pattern profile of the sample chromatogram can be compared to the pattern profile of known accelerant chromatograms within the same boiling-point range. This can then be followed by a comparison of significant similarities in retention times, peak height, and peak ratios of known accelerants, while keeping in mind the contributing factors for dissimilarities such as states of evaporation, formula changes, and additional contamination. If significant major peaks or a series of minor peaks are missing within the middle of the sample's chromatographic pattern, then there is a strong possibility that an identification cannot be made. The contribution of a significant number of additional peaks from the debris itself located between and over the peaks from an accelerant may also prohibit an identification.

Analytical Interpretation: GC/MS and Macros

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Gas chromatography/mass spectrometry (GC/MS) has become an important tool in the analysis of fire debris samples for flammable liquids. Although it provides many benefits to the chemist, the complexity of the analytical interpretation is increased.

The use of a mass spectrometer detector instead of a flame ionization detector will generate a great deal of additional information. The computer on a FID stores one data point, the FID response, per time unit. A GC/MS will capture and store a data point for each AMU over the scanning range (typically 30 - 300 AMU) per time unit. On a Hewlett-Packard Pascal-based computer, a typical case sample can require a quarter megabyte of hard disk space. In order to interpret such vast amounts of data, there must be some way of organizing and presenting it in a logical and coherent manner.

I first began using GC/MS on arson samples in 1987. At first people in other laboratories said that while MS may be necessary on certain difficult samples, they would not like to use it routinely because of the amount of analyst time required to sit at the computer and generate the selected ion profiles or do the library searches that are necessary to characterize the sample. Fortunately, Hewlett-Packard (and other manufacturers of desktop mass spectrometers) include some form of macro writing capability for their computer systems. By using macros, the repetitive series of keystrokes and commands that are used to work with the data can be automated, freeing the analyst from the computer terminal.

My initial work with MS of fire debris samples concentrated on:

- Determining what, of all the MS information generated, is needed for the identification of an accelerant.

- Writing a macro that will extract the essential information and present it in a format that will allow the analyst to make a quick and accurate determination.

The first question had already been addressed by several authors. The hydrocarbons that make up most flammable liquids fall into a few general classes. By selecting certain groups of characteristic ions, one could generate selected ion chromatograms for each of these classes (Figure 1). In our laboratory, we generate five profiles for a sample: the total ion chromatogram (TIC), and ion chromatograms specific for aromatic compounds, paraffins, indanes, and naphthalenes. A macro that will automatically generate and print these chromatograms is very simple and the printout appears in a matter of minutes (Figure 2). This macro runs during the time required

Characteristic Fragment Ions for the Hydrocarbon Chemical Classes	
Chemical Class	**Fragment Ions**
Paraffins	57+71+85+99
Aromatics	91+105+119-93
Naphthalenes	128+142+156
Indanes	117+131+145

Figure 1.

for the GC oven to cool back down to its initial temperature. No extra analytical time is needed for MS in contrast to using an FID.

The majority of cases can be interpreted from this information alone. The ASTM classification guidelines specify which features must be apparent in each pattern before a flammable liquid can be identified as being present in the sample (Figure 3). One advantage of MS is that, even in situations where the TIC cannot be conclusively interpreted, such as when peaks from pyrolyzates are very large, characteristic aromatic and paraffin profiles may be generated. MS allows conclusive determinations to be made in samples where an FID pattern is not easily interpretable (Figure 4).

There are situations where it is helpful to perform a library search on several peaks in the chromatogram. This can arise when, again, the TIC is complex with many unrecognizable peaks, or alternatively when there are only a few peaks present. Most GC/MS systems come with some type of library of standard mass spectra installed (such as NBS, WILEY, or NIST), and the capability of creating your own library of spectra. The process of searching a peak against one of these standard or user-created libraries and reporting the results of the search can be entirely automated through the use of macro programming.

There are some inherent problems in performing library searches on hydrocarbons:

- ♦ Many isomers have very similar mass spectrums and the computer search algorithm may not be able to distinguish among them. For example, on my system 1,2,4-trimethylbenzene is always identified as 1,2,3-trimethylbenzene.
- ♦ The 25-meter columns that I use cannot resolve all the components of a complex, hydrocarbon mixture. Peaks may coelute, complicating the library search.
- ♦ None of the libraries contain all the compounds that can be present in flammable liquids.

Because of this, it is dangerous to assume that the chemical identified by the computer search algorithm is correct.

I decided to try to write a library search macro that would reduce the possibility of misidentifications. While many isomers may have similar mass spectra, they will have different retention indices for the column and temperature program used. I created my own mass spectral library of compounds encountered in fire debris analysis that also included the retention index for that compound. I then wrote a macro that added a retention index filtering step. The result is a more accurate listing of the peaks identified in the TIC (Figure 5).

While this macro works very well, it does involve a lot of set up time in creating the user library and ensuring that the retention indices of the peaks are calculated correctly. You may not find that it is worth the effort, but I am willing to share my data files with anyone who wishes to attempt something similar.

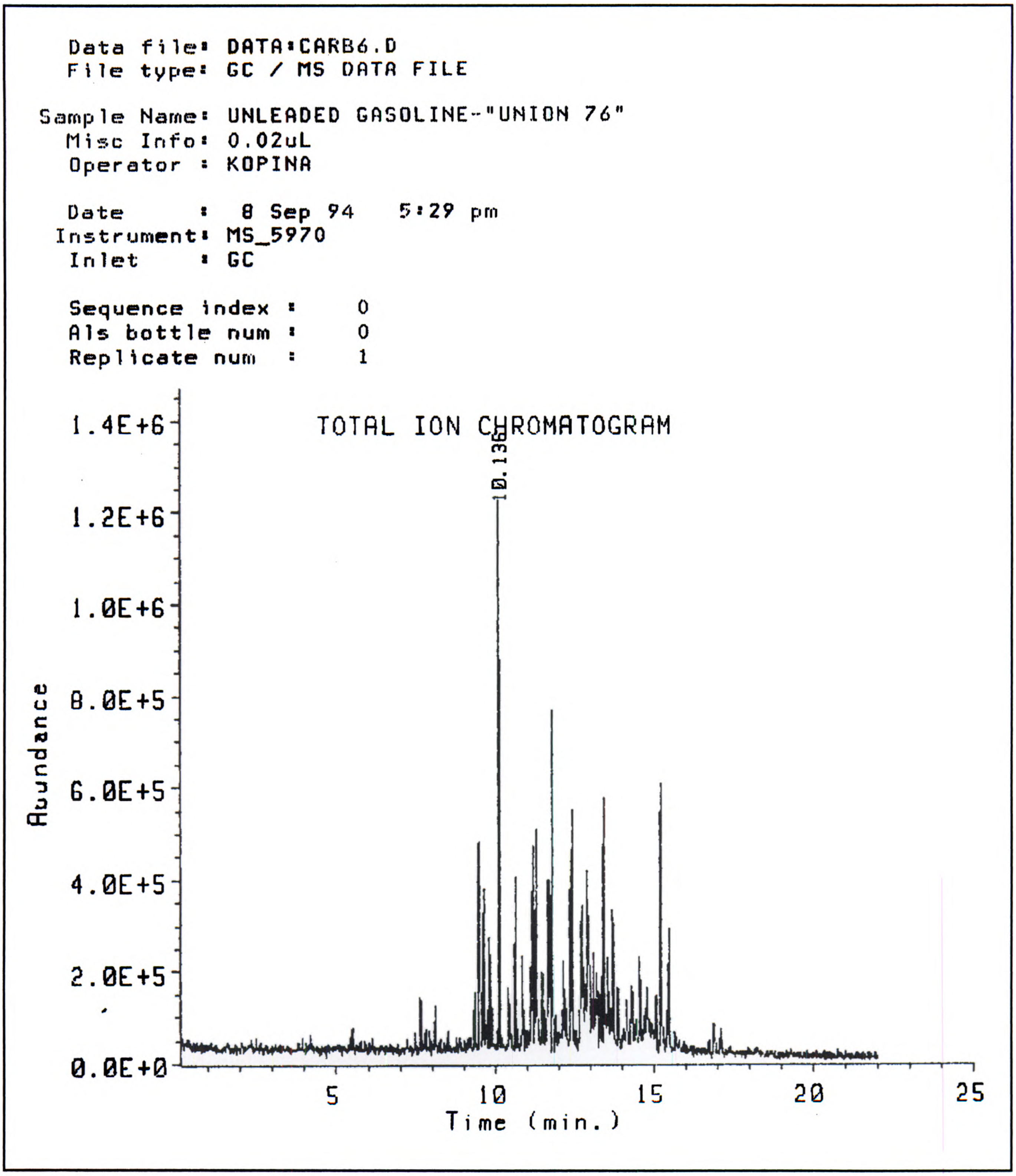


Figure 2. Simple macro output: TIC and 4 groups of ion profiles (gasoline - weathered 75% evap.)

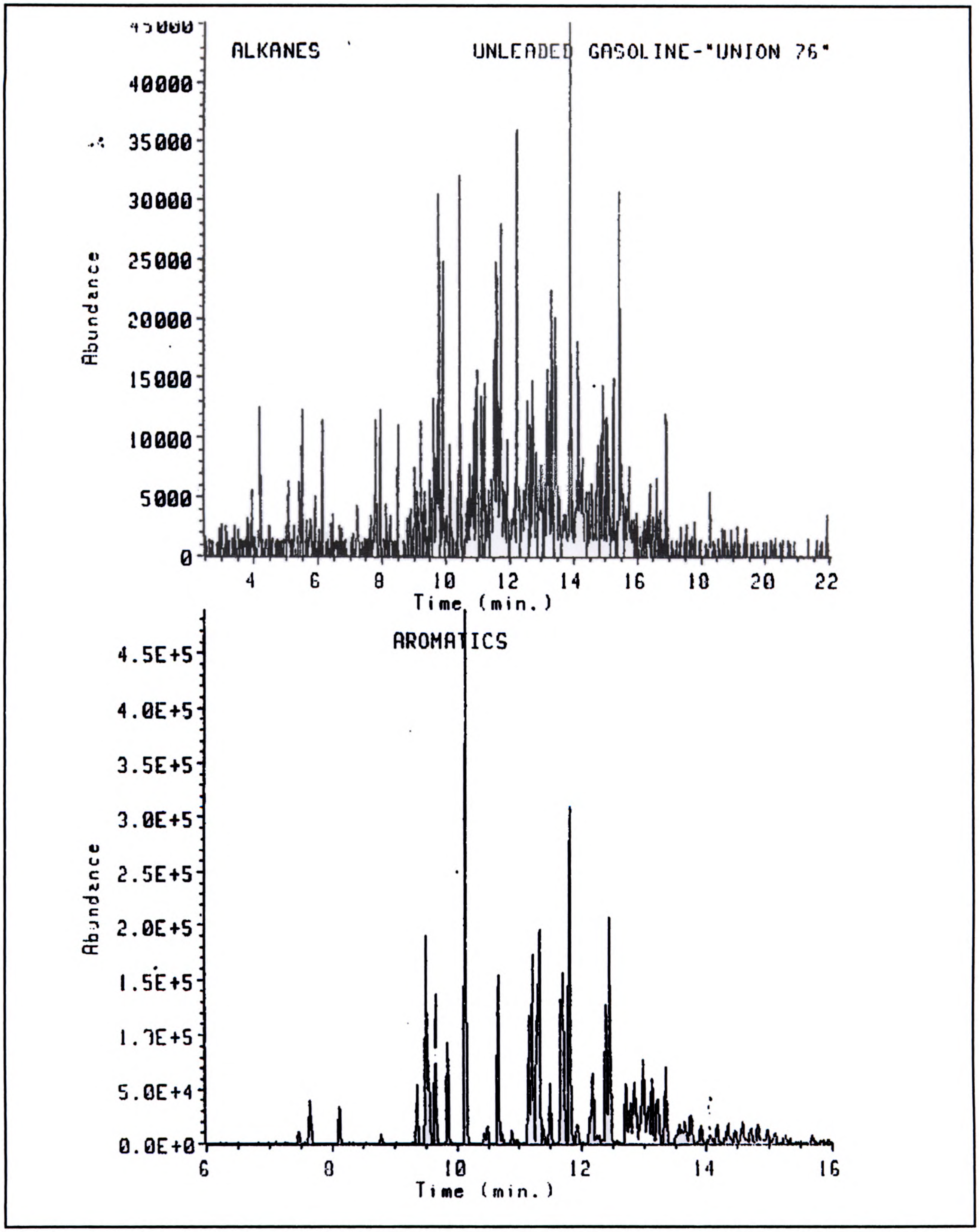


Figure 2. Continued (gasoline).

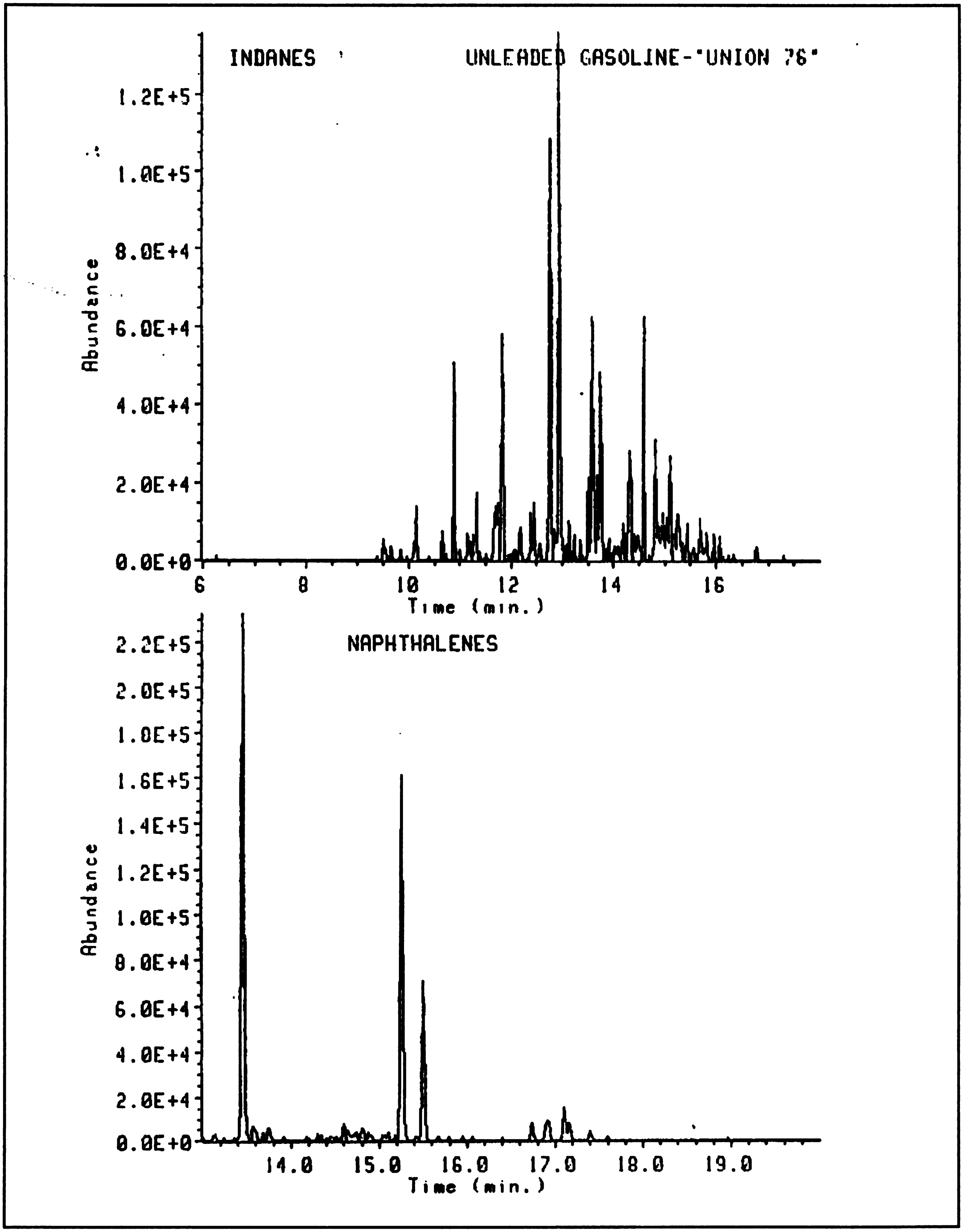


Figure 2. Continued (gasoline).

Class	Hydrocarbon Range*	Chemical Criterion
Light Petroleum Distillates	C5 to C11	Alkanes: Characteristic Pattern Cycloparaffins: Characteristic Pattern Aromatics: Benzene to C9 Aromatics Naphthalenes: None
Light Petroleum-Based Products	C5 to C11	Alkanes: May Be Present Cycloparaffins: May Be Present Aromatics: May Be Present Naphthalenes: None Other: Alcohols, Acetates, or Ketones May Be Present
Gasoline	C5 to C14	Alkanes: Present, But Variable Cycloparaffins: Not Significant Aromatics: Characteristic Pattern Naphthalenes: Characteristic Pattern Dihydroindenes: Characteristic Pattern
Medium Petroleum Distillates	C8 to C12	Alkanes: Characteristic *n*-alkanes Cycloparaffins: Characteristic Pattern Aromatics: Not Significant Naphthalenes: Not Significant
Isoparaffin Products	C7 to C14	Alkanes: Characteristic Isoparaffins Cycloparaffins: None Aromatics: None Naphthalenes: None
Heavy Petroleum Distillates I	C8 to C18	Alkanes: Characteristic *n*-alkanes Cycloparaffins: Not Significant Aromatics: May Be Present Naphthalenes: May Be present
Heavy Petroleum Distillates II	C9 to C23	Alkanes: Characteristic *n*-alkanes Cycloparaffins: None Aromatics: May Be Present Naphthalenes: May Be Present

* These ranges represent the extreme limits for the class. Many products will exhibit narrower ranges than those listed.

Figure 3. Classification guidelines using GC/MS.

Data file: DATA:PROF4.D
File type: GC / MS DATA FILE

Sample Name: SAMPLE 4
Misc Info: LIQUID
Operator : NOWICKI

Date : 26 Apr 95 1:48 pm
Instrument: MS_5970
Inlet : GC

Sequence index : 0
Als bottle num : 0
Replicate num : 1

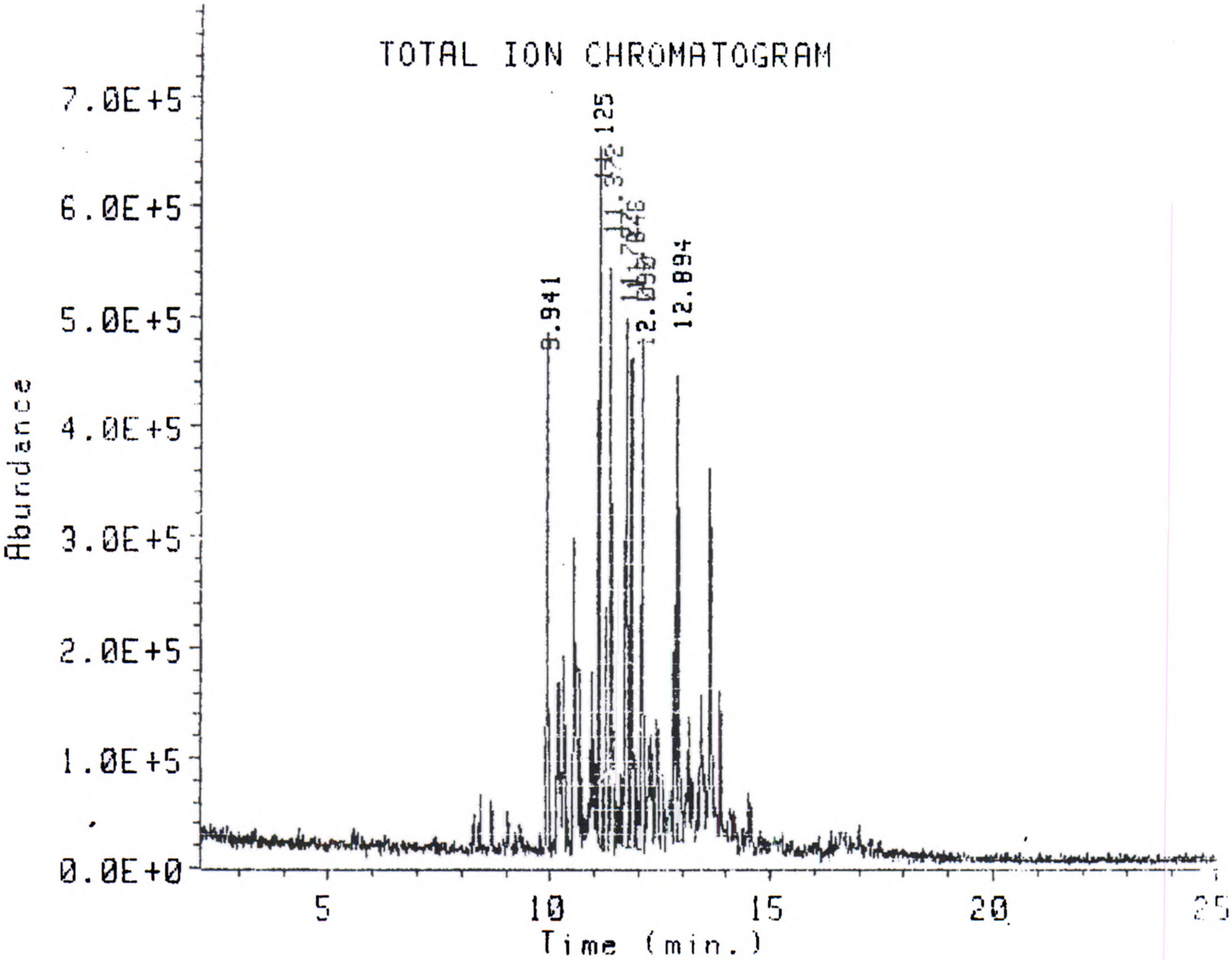


Figure 4. TIC and paraffin and aromatic profiles of unknown sample.

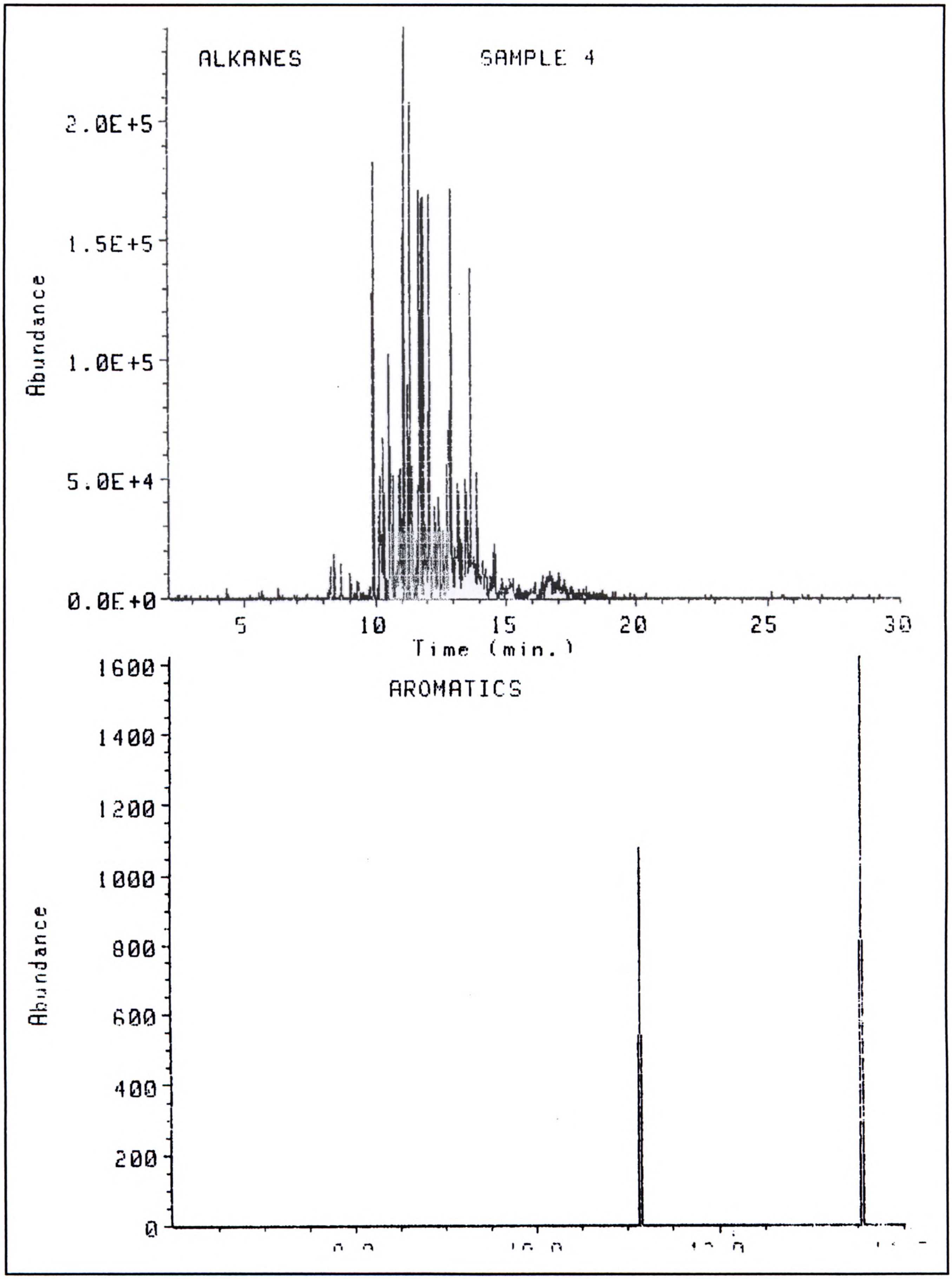


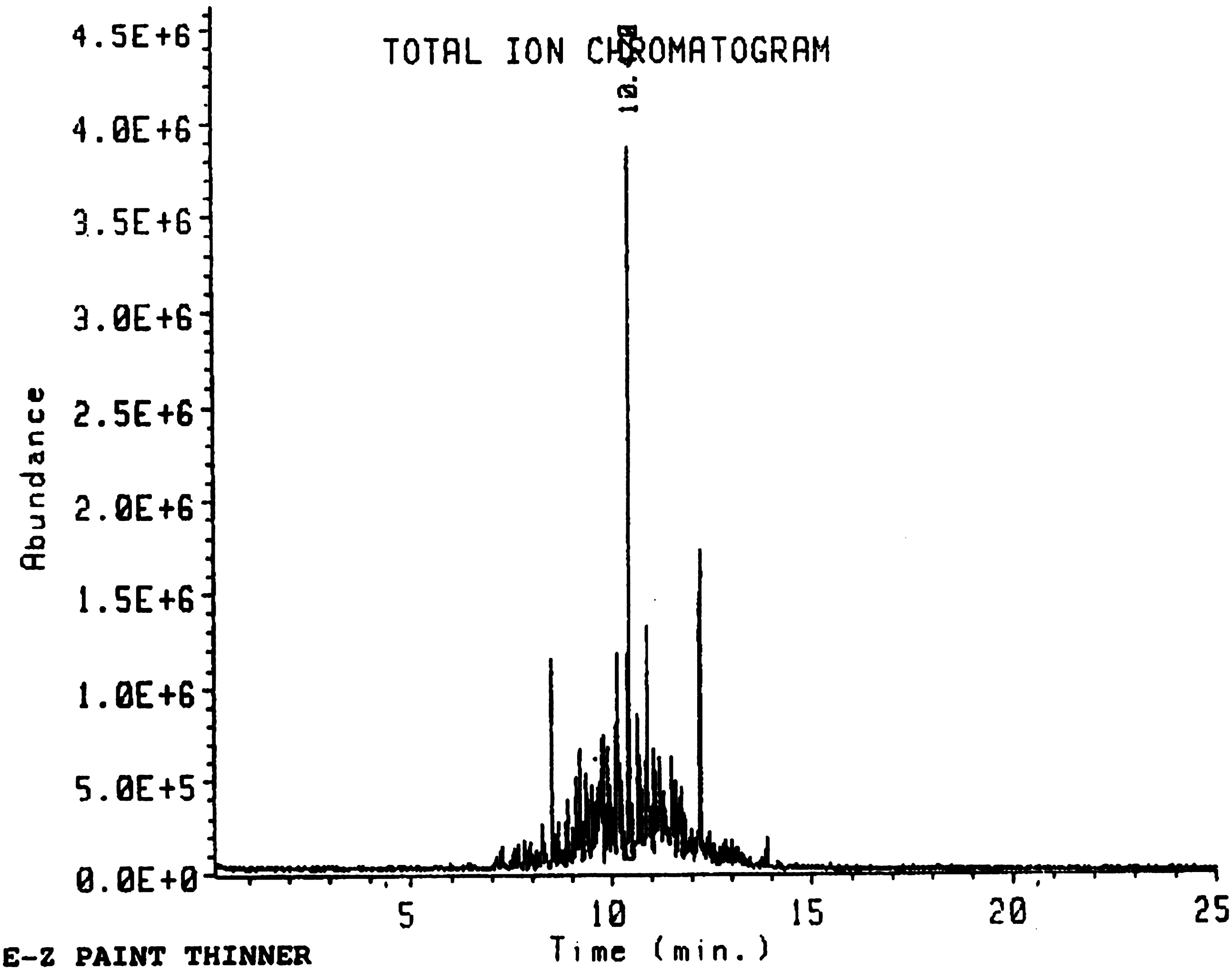
Figure 4. Continued

Data file: DATA:CARB5.D
File type: GC / MS DATA FILE

Sample Name: E-Z PAINT THINNER
Misc Info: 0.02uL
Operator : KOPINA

Date : 15 Sep 94 4:13 pm
Instrument: MS_5970
Inlet : GC

Sequence index : 0
Als bottle num : 0
Replicate num : 1



E-Z PAINT THINNER

PEAK#	RET TIME	RI	QUALITY	COMPOUND
1	8.526	899	91	Nonane
2	10.156	984	95	Benzene, 1,2,4-trimethyl-
3	10.468	998	93	Decane
4	10.688	1011	64	Benzene, 1,2,3-trimethyl-
5	10.919	1025	93	Nonane, 2,2-dimethyl
6	12.256	1099	46	Undecane

Figure 5. Output from library search macro.

Private Laboratories and Ignitable Liquid Analyses

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The results of the analyses of fire debris samples can be of very great importance in fire loss cases. Unfortunately, in the private sector, there is considerable variation in the quality of the output, which results from considerable variation in the training, equipment, and techniques of the laboratories that offer this specialty. The problems are in various areas:

- The analyst does not have proper training in chemistry.
- The analyst does not have experience in fire debris analysis.
- The technique (equipment and/or procedure) is not proper.
- The sample results are interpreted incorrectly.
- Other problems.

The first example, which illustrates problems in each of the areas, involves a case in which a fire investigator investigated a fire in which a residence was essentially completely destroyed. A sample of debris from the scene was analyzed by atomic absorption spectroscopy for lead; 83 ppm were found. The investigator concluded that gasoline was present in the debris, since such a level of lead was abnormally high. He stated that he had one chemistry course in the 1940s, and that he had no training in AA, but that he had read the manufacturer's instructions for the equipment, and had supervised the analysis. Unfortunately (for him), he had testified in another case that background levels of lead were somewhat higher than 83 ppm. And in one of his poorer moments in court, at the trial the opposing counsel asked what the name of the equipment was that he used for the lead analysis. He could not remember and had to leave the stand, and go get his notes in order to correctly identify the equipment he was an expert on.

Another analyst proposed the use of second derivative ultraviolet for ignitable liquid analyses. To my knowledge, no one else who conducts fire debris analysis has given any support to that proposal.

In the following cases, although the analysts had training in chemistry and fire debris analysis, and used gas chromatography or gas chromatography/mass spectrometry (GC/MS) in the analyses, they identified ignitable liquids when the evidence did not support such a conclusion.

In a fire case, the analyst concluded that gasoline was present in two samples. Comparison of the unknowns and a gasoline reference showed that the patterns did not match. When asked about the lack of corresponding peaks, the analyst replied that weathering changes the retention times, and therefore, it is not expected that the peaks would match. Although his report stated that the patterns matched gasoline in the medium and heavy ranges, the runs involving the unknowns were stopped before the heavy range. When asked about that, he replied that the heavies would have been there if he had let the runs go that far.

In a case involving a different laboratory, the analyst testified in deposition that there was no doubt that the sample contained gasoline. He ran only four reference materials: gasoline, kerosene, and Number 1 and Number 2 fuel oils; the unknown was closest to gasoline. He could not identify any of the peaks in the unknown or in the gasoline chromatogram, and he said that he never ran any carpet, pad, etc., because the materials vary. When asked about the lack of matching peaks, he stated that weathering changes the distances between the peaks. Ironically, his report,

which more accurately reflected the situation than did his testimony, stated that "Sample 2 indicated the presence of characteristics suggestive of the presence of petroleum distillates comparable to gasoline." The samples were then submitted to another laboratory, which analyzed them using GC/MS; they reported the results as being negative.

A home was destroyed by a very severe fire. The next day there were heavy thundershowers. Afterward, samples were collected and submitted for analysis. The samples were analyzed by GC/FID on only one column. It was reported that two of the samples contained the same type of "... low-boiling range highly flammable liquid, such as lacquer thinner." The analyst opined that the largest peak in their chromatograms was ortho-xylene (a rather unusual material for Mom and Pop to use to burn their home). The samples were sent to another laboratory, which concluded that the samples were negative, and that the patterns resulted from background pyrolysis products. The large peak was not ortho-xylene, but rather styrene.

Does the use of GC/MS eliminate errors? Not necessarily. For example, an environmental laboratory started conducting fire debris analyses. If they found BETX (benzene, toluene, ethylbenzene, and xylene), they would report that gasoline was present, without utilizing pattern recognition or any ion profiles. The analyst did not have any carpet or pad reference chromatograms, and was unaware that the BTEX series is very common in burned carpet material.

There are some cases in which the samples are analyzed properly and the results interpreted properly, but there are other problems. For example, kapak bags for a period of time were found to incorporate their own ignitable liquid, a medium-range material called an isoparaffinic solvent.

There was a fire in Oklahoma during the summer that burned a restaurant almost to the ground. The Fire Marshal investigated and reported that there was no evidence that the fire was other than accidental. After about a week, there was an anonymous call that the fire was set, and to look in the foyer. The investigators returned to the scene, which had been sitting in the summer heat and wind during this time; they detected the odor of gasoline in the foyer. When the sample was analyzed, gasoline was found, in fact, fresh gasoline.

In some instances the analyst may extend his conclusions beyond what the data allow. For example, there was a case in which a number of samples were submitted to a laboratory, which reported that Number 2 fuel oil was present. Since there was a 1,000-gallon tank that had leaked a considerable amount of liquid into the building, such a result was not unexpected. What was unexpected was the conclusion of the analyst that "based on the results of these tests, we conclude the fuel oil was used as an accelerant in this fire."

Perhaps the most unusual range of laboratory capabilities that I have encountered is the one in which the analyst not only conducts fire debris analysis, but she also sells artwork and custom fits bras in the same office.

In summary, there are many private laboratories in which the analysts are well-trained in chemistry and fire debris analysis, and whose conclusions are well based. On the other hand, the results reported by some of the laboratories should be reviewed very carefully before being accepted.

Considerations in the Analytical Interpretation of Gas Chromatographic Test Results of Fire Debris

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There are many factors which may distort the chromatographic profile of a recovered accelerant from a fire scene. These can be grouped into two classes: those which are the result of the analytical process; and those which occur external to the laboratory. The analyst has control over the first class and must be aware of the distortions potentially caused by the second class.

Accurate interpretation of fire debris gas chromatograms depends on the ability of the recovery method to accurately recover a representative subsample from the enclosed sample. Recovery methods used for volatile fire debris should be tested by analyzing a standard mixture (such as the ATF recommended 1:1:1 gasoline:MPD:HPD mixture) and comparing results to a neat (liquid) analysis of the same standard. Headspace techniques, whether static subsample or adsorption/elution, rely on the equilibrium between the liquid and gas phases of the enclosed sample. This equilibrium varies depending on the time and temperature of the collection phase and the concentration of the recovered fuel. Slides will demonstrate some of the affects these factors have on the final chromatographic profile.

The analyst must have a working knowledge of several other external factors which affect the final chromatographic profile. These may include evaporation, pyrolysis addition, and microbial degradation. Perhaps the best way to become familiar with these is by analyzing materials and fuels from full-scale test burns. (Of course, there is no replacement for experience and the continual addition to the laboratory chromatogram reference collection).

Prior to the collection of the sample, evaporation and pyrolysis addition can alter the profile of the suspected accelerant. Evaporation results in a somewhat predictable loss of those compounds with higher-vapor pressures. The higher the vapor pressure, the greater the loss due to exposure. Pyrolysis addition is often flagged by the presence of styrene. Several other indicators are commonly present which may signify the presence of pyrolysis. Sample chromatograms will demonstrate some of these.

Bacterial degradation can alter the composition of a sample both before it is collected as well as after. This degradation will most likely be observed in a sample media such as organic soils or anything which will support large populations of bacteria. Hydrocarbon compounds with a normal-alkane character are the most susceptible to this alteration. Simple aromatic compounds will also be affected, but aromatic compounds with highly branched sidechains are less likely to be consumed by bacteria. Again, slides will demonstrate this phenomenon.

Capillary gas chromatography is used to compare the relative concentration of hydrocarbons in order to distinguish different classes of fuels. This technique can also be extended to distinguish fuels within a classification. The refining process used to manufacture gasoline produces a chromatographic profile which contains a great deal of information. The fraction of gasoline with a volatility ranging from n-

pentane to n-octane contains most of the discriminating information. Sample preparation, analytical parameters, evaporation, pyrolysis addition, and other factors need to be considered when attempting to compare a gasoline sample recovered from a fire scene to a standard liquid standard.

Analysis Protocols and Proficiency Testing in Fire Debris Analysis

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and

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Laboratories conducting fire debris analysis need more than analytical methods to produce quality results. They need an overall protocol that includes quality assurance procedures, recovery procedures, instrumental analysis methods, and interpretation guidelines. This paper discusses the basis for a standard protocol for the analysis of fire debris samples. It offers guidelines for sample recovery, sample analysis, and quality assurance procedures. A protocol for proficiency testing (part of quality assurance procedures) is addressed separately. This protocol is limited to the recovery and identification of commercially available flammable and combustible liquids.

Much of this work is derived from developmental work done in conducting the Bureau of Alcohol, Tobacco and Firearms (ATF) Arson Accelerant Detection Courses, which began in 1980 and were published in the 3 versions of the course books (1980, 1983, and 1986). In 1988 the American Society for Testing and Materials (ASTM) approached the forensic science community to see if there was interest in reviving the E30 Committee on Forensic Sciences. A positive response led to the committee becoming active. The first standards written which came from the criminalistics' subcommittee addressed methods of recovering ignitable liquids from fire debris and a test method for instrumental analysis. These standards were written by a task group from the forensic community and embody procedures and analysis schemes first promulgated at the ATF Arson Courses. Dr. Phillip Wineman, Richard A. Strobel, and Richard E. Tontarski, Jr., laid much of the groundwork for these methods by leading more than 300 students (30 classes from 1980 to 1987) through a series of experiments that demonstrated the advantages and disadvantages of the various sample preparation techniques. This allowed the students to "discover" the analysis scheme that many laboratories use today. Those students also deserve credit for their insights they brought to the classes. These insights have benefited future classes and ultimately made their way into the ASTM standards.

INSTRUMENTAL ANALYSIS

Chromatographic Characterization

Gas chromatographic (GC) characterization by pattern recognition is the method of choice in identifying petroleum products recovered from fire debris samples. The variety of commercially available petroleum-based products is quite large. Only those of suitably low flashpoint and volatility are commonly used to accelerate fires. The heaviest products such as oils, waxes, and asphalts can (for the most part) be ignored. Because of the refinery processes used to make these products and the methods of their distribution for end use, the products can be placed into a general classification scheme based on their overall chromatographic patterns. A large number of compounds and their relative ratios give characteristic patterns when separated by GC which

can be compared to standards and qualitatively identified (Clark and Jurs 1975; 1979).

In 1982 ATF and the National Bureau of Standards collaborated in examining a wide variety of commercially available flammable and combustible liquids (*Arson Analysis Newsletter* 1982). By examining the resulting GC patterns, they were able to classify petroleum products into a relatively simple scheme of five basic classes; this scheme is shown in Table 1. Since that time the variety of commercially available products has increased with many specialty products fitting a miscellaneous category. In response, a new classification scheme which addresses many of these specialty products has been developed (ASTM E1387-90 1994); this scheme is shown in Table 2. This classification scheme is based on retention time windows or peak spread of the compounds eluting as defined by the *n*-alkane carbon number. Evaluation of these products requires GC conditions that can separate compounds from butane (C_4) to tricosane (C_{23}). Defining the separation needed, rather than a specific column and GC conditions, allows for flexibility in the column and conditions which can be used. Figure 1 shows the separation of the test mixture recommended in ASTM E1387-90 for separation parameters. Under the conditions shown in Figure 1, a resolution of 2.9 is achieved between m-ethyltoluene and o-ethyltoluene (the two closest peaks in the test mixture). Baseline separation is defined as a resolution equal to or greater than 1.5 (McNair and Bonelli 1969). (NOTE: The 7 ASTM E-30 committee standards on fire debris analysis were due for their 5-year renewal in 1995. All the standards have been changed to some degree, most notably in the title. The phrase "flammable or combustible liquid residues" has been changed to "ignitable liquid residues." Substantial revisions to E1387-90 were made to make the requirements of the test method more explicit. The voting on the revised standards at the main committee level closed July 6, 1995. Because the revised standards had not received society approval at the time of publication of this paper, they could not be referenced. For future reference, readers are advised to refer to the latest available versions of these standards.)

Table 1

ACCELERANT CLASSIFICATION SYSTEM†

† Taken from 1983 training material, ATF Arson Accelerant Detection Course

CLASS NO. (CLASS NAME)	"PEAK SPREAD" (BASED ON N-ALKANE CARBON NO.S)	EXAMPLES
1 Light Petroleum Distillates (LPD)	C_4 - C_8	Petroleum ethers, pocket lighter fluids, rubber and rubber cement solvents, Skelly solvents, Lacquer thinner*
2 Gasolines	C_4 - C_{14}	Automotive gasoline of all brands and grades, including gasohol. Coleman fuel**
3 Medium Petroleum Distillates (MPD)	C_8 - C_{12}	Charcoal starters - some brands, paint thinners (oil base), mineral spirits, naphthas/"Dry" cleaning solvents
4 Kerosine (No. 1 fuel oil)	C_9 - C_{16}	Charcoal starters - other brands, lamp oils, no. 1 diesel fuel, insect sprays, Jet-A (Aviation) fuel
5 No. 2 Diesel Fuel No. 2 Heating Fuel	C_{10} - C_{23}	

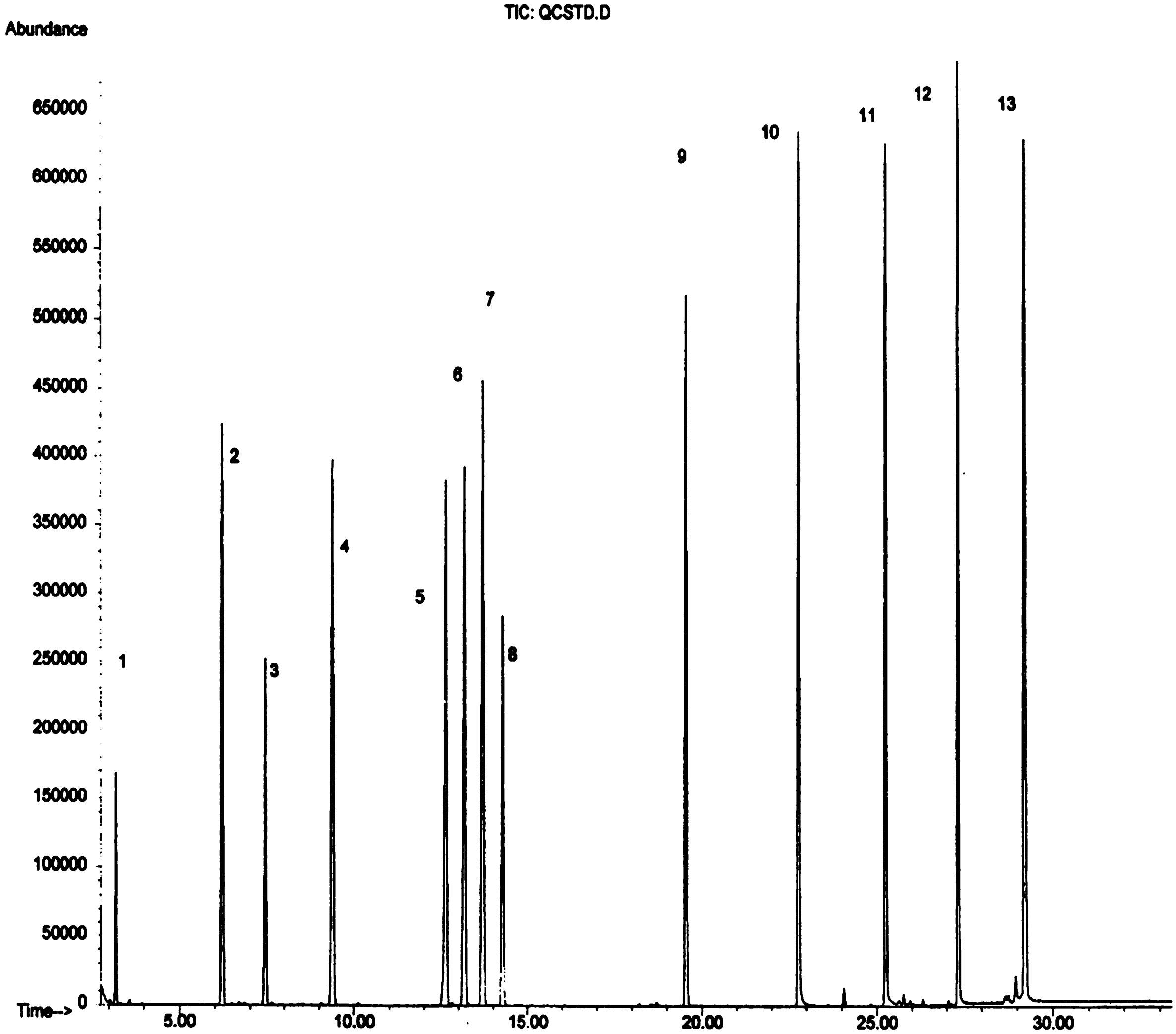
* NOT A PETROLEUM PRODUCT BUT INCLUDED IN THIS CLASS, FOR CONVENIENCE BASED ON PEAK-SPREAD.

** THIS PRODUCT IS "STRAIGHT RUN" GASOLINE, LOWER IN AROMATICS AND OF NARROWER PEAK-SPREAD (C_6 - C_{12}) THAN AUTOMOTIVE GASOLINES.

Table 2

Ignitable Liquid Classification System

CLASS NUMBER (CLASS NAME)	"PEAK SPREAD" BASED N-ALKANE CARBON NOs (UNEVAPORATED LIQUID)	EXAMPLES
1 Light Petroleum Distillates (LPD)	C_4 - C_{11}	Petroleum ethers, Pocket lighter fuels, some rubber cement solvents, VM & P Naphtha, Skelly solvents, some camping fuels
2 Gasoline	C_4 - C_{12}	All brands & grades of automotive gasoline, including gasohol.
3 Medium Petroleum Distillates (MPD)	C_8 - C_{12}	Mineral spirits, some paint thinners, some charcoal starters, "Dry-cleaning" solvents, some torch fuels. Some solvents for insecticides, polishes, and some lamp oils.
4 Kerosine	C_9 - C_{16}	Kerosine, No. 1 fuel oil, Jet-A (aviation) fuel, solvent for some insecticides and polishes, some paint thinners, some lamp oils.
5 Heavy Petroleum Distillates (HPD)	C_{10} - C_{23}	Diesel fuel, No. 2 fuel oil (home heating oil).
0 Miscellaneous	Variable	Single compounds, turpentine, specialty mixtures which cannot be further classified into one of the categories below.
0.1 Oxygenated Solvents	Variable	Alcohols, esters, ketones
0.2 Isoparaffins	Variable	Isoparaffin products, some charcoal starters, some copier fluids, some aviation gasolines, some lamp oils, some solvents for insecticides and polishes, some camping fuels.
0.3 Normal alkanes	Variable	Specialty products formulated from normal alkanes. Some lamp oils, some solvents for insecticides and polishes
0.4 Aromatic solvents	Variable	Light, medium and heavy "aromatic naphtha" used as solvents for paints and plastics
0.5 Naphthenic/paraffinic solvents	Variable	Specialty solvent/fuel products made from Class 3 or Class 4 distillates treated to remove normal alkanes and aromatics



PEAK NUMBER	COMPOUND	RETENTION TIME (MIN)
1	Hexane	3.2
2	Toluene	6.2
3	Octane	7.5
4	p-Xylene	9.5
5	m-Ethyltoluene	12.7
6	o-Ethyltoluene	13.2
7	1,2,4-Trimethylbenzene	13.8
8	Decane	14.3
9	Dodecane	19.6
10	Tetradecane	22.8
11	Hexadecane	25.3
12	Octadecane	27.4
13	Eicosane	29.2

Instrumental analysis conditions:

Hewlett-Packard 5890 GC with 5971A MSD

Column: HP-1 (100% methyl silicone) 25 m x 0.2 mm id with 0.5 micron film thickne

Carrier gas: Helium at approximately 0.6 ml/min

Temperature Program: 60 degrees C for 3 min, ramp 5 degress min to 120 degrees C ramp 12 degrees/min to 280 degrees C, hold 5 min.

Figure 1. ASTM E1387 Standard test mixture.

GC - Flame Ionization Detector (GC-FID)

Extracts isolated from fire debris are analyzed using GC with a FID. The column, temperature program, and carrier gas flow rate should be optimized to produce chromatograms suitable for pattern recognition. Most petroleum products are composed of hydrocarbons. Nonpolar capillary columns are the column of choice for analyzing these products. While a column as short as 15 meters provides enough separation for pattern recognition, longer columns provide greater resolution which is desirable when a specific detector such as GC/mass spectrometry (GC/MS) is used.

ASTM E1387-90 - *Standard Test Method for Flammable or Combustible Liquid Residues in Extracts from Fire Debris Samples by Gas Chromatography* provides guidelines for the analysis of fire debris samples. The test method covers recommendations on apparatus, reagents, sample handling, calibration, interpretation guidelines, and report wording.

GC/MS

The complexity of most petroleum products recovered from fire debris permits class identification based on pattern recognition. Sometimes more specific information is needed than can be provided from GC-FID patterns alone. For example, pattern recognition cannot be applied to products which contain single or few peaks. In other samples, volatile materials from the matrix may obscure the hydrocarbon pattern of interest. In these cases, the use of a more specific detector can provide more definitive information.

Analysis times giving baseline resolution of all the components of petroleum products are too long to be useful in routine fire debris analysis. Sanders and Maynard (1968) identified hydrocarbons in gasoline between C_3 and C_{12} using a 200-foot column with a total analysis time of 115 minutes. Baseline resolution is necessary for unknown component identification; however, it is not necessary for mass spectral interpretation of petroleum products of known composition. Some compromise between resolution and speed of analysis must be made. The test mixture in Figure 1 meets ASTM E1618-94 - *Standard Guide for Ignitable Liquid Residues in Extracts from Fire Debris Samples by Gas Chromatography/Mass Spectrometry* resolution requirements with an analysis time of slightly more than 33 minutes.

CHROMATOGRAPHIC INTERPRETATION

Chromatographic interpretation requires an understanding of the refinery process. The chromatographic patterns of petroleum products are a direct result of distillation, blending, and treatment to produce products of desired chemical and physical properties for the industry. Several references are available for the study of refinery processes (Gary and Handewerk 1994; Speight 1991). Forensic chemists performing fire debris analysis should have a thorough understanding and be able to explain how crude oil is refined to produce commercially available ignitable liquids.

The first step in conducting fire debris analysis is building a standards library of petroleum products run under the GC conditions chosen for analysis. Products from each of the different classes should be obtained and run on the GC; this library should be updated as new products become available. If a laboratory decides to change GC conditions, all samples in the library need to be rerun under those same conditions. It is imperative that unknowns are compared to standards run under the same GC conditions. Figures 2 and 3 show examples of different classes of petroleum product run under analysis conditions that permit pattern recognition identification.

Flammable or combustible liquids recovered from fire debris have normally been exposed to heat and, therefore, have lost some of the more volatile compounds through evaporation. The library of standards should include standards of common products in various stages of evaporation (Guinther *et al.* 1983). Recommendations for gasoline include standards of unevaporated, 20%, 50%, 75%, 90%, 98%, and 99% evaporated gasoline. In highly-evaporated gasoline (more than 90%) several peaks in the C_8 - C_{12} range, associated with normal alkanes in medium petroleum distillates, may appear in the chromatographic pattern. However, while the overall pattern is in the medium petroleum distillate range, the dominate peaks are naphthalene and 2-methylnaphthalene (not normal alkanes). In GC-FID pattern recognition, this can be verified by noting that the retention times do not match those of the normal alkanes. With GC/MS, these peaks can be verified by their mass spectra.

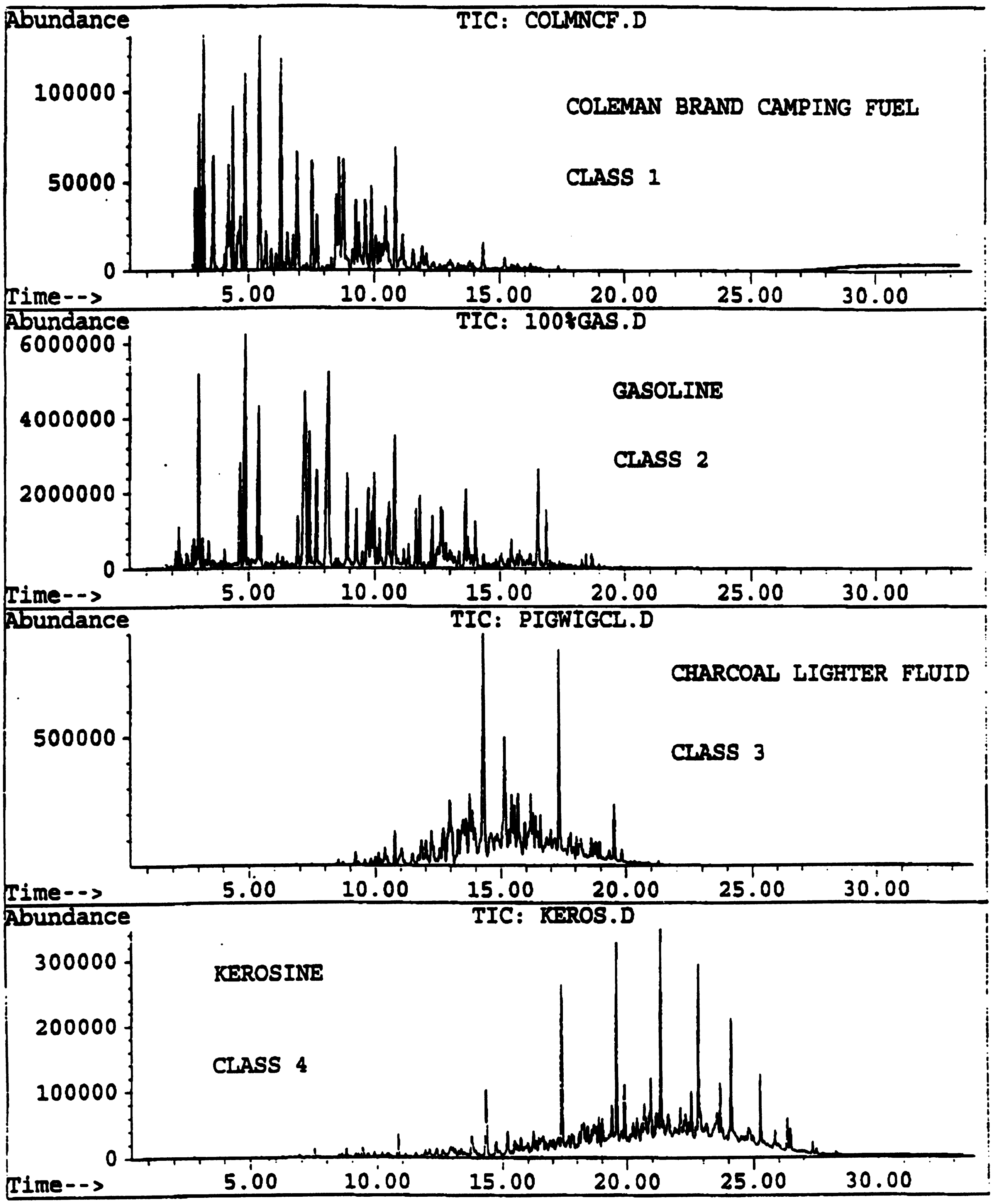


Figure 2. Chromatograms of Class 1, 2, 3, and 4 ignitable liquids.

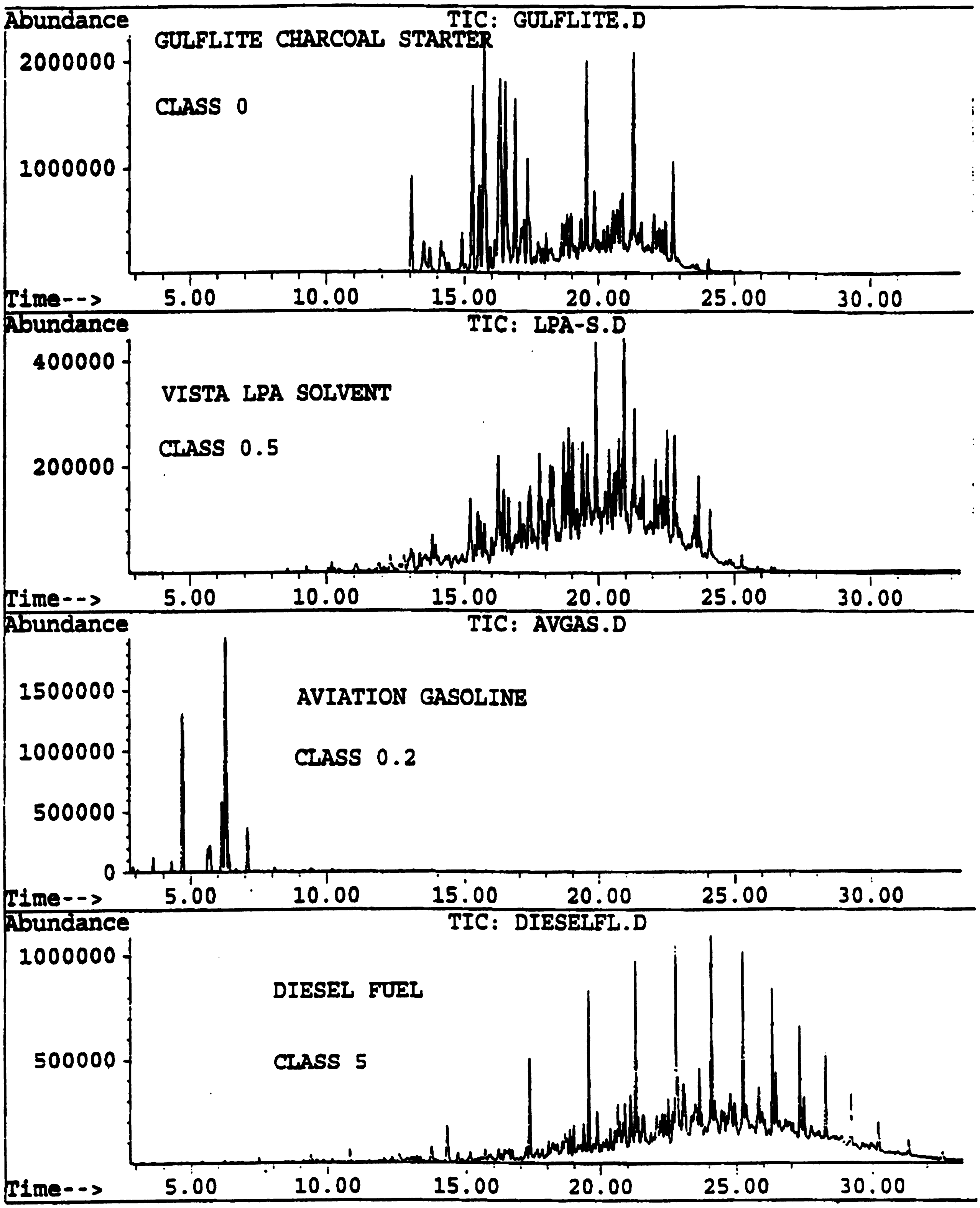


Figure 3. Chromatograms of Class 0, 0.2, 0.5, and 5 ignitable liquids.

The sample preparation technique most frequently used should be considered when building the library. Neat liquid samples can be compared to unknowns isolated by most adsorption/elution techniques. However, the patterns obtained from headspace samples may differ enough from neat liquid patterns to warrant building a separate library of headspace patterns if the technique is used extensively.

Table 3 gives a checklist developed for the ATF Arson Accelerant Detection Course in 1986 that can be used in obtaining a chromatogram suitable for pattern recognition interpretation and steps used to interpret the chromatogram. The first step involves obtaining a chromatogram in which all the major peaks are on-scale. Since pattern recognition involves not only comparison of retention times, but also evaluation of relative peak-height ratios, it is important to have a chromatogram that illustrates all the relative ratios of peaks present. Next, the analyst should note the retention time window in which peaks appear. This is characterized in the classification scheme in Table 2 as peak spread based on the *n*-alkane number, which approximates the boiling point of the compounds eluting from the column. Since actual retention times vary with column and GC conditions, basing peak spread on the *n*-alkane elution window provides a standard that applies to all conditions.

It may not be possible to identify products in the miscellaneous class by GC-FID pattern recognition. In the case of single compounds such as alcohols, acetone, and toluene, identification cannot be made on the basis of retention time on a single column. Some lacquer thinners and specialty products contain only a few compounds and do not contain enough points of comparison for pattern recognition. Other techniques such as GC/MS are needed to confirm the identity of these compounds.

Unknown chromatograms rarely match standards exactly peak for peak. Samples obtained from fire debris will likely show some loss of volatile compounds because of evaporation. Also, depending on the sample preparation technique used to isolate the sample, the full range of a combustible or flammable liquid may not be recovered. For example, all headspace techniques (both static and dynamic) usually do not recover hydrocarbons beyond the C_{17} range from burned debris samples. The important point to remember is that compounds should not be selectively missing. However, if more volatile compounds are present, but several less volatile compounds are missing while some are present, the analyst should immediately be suspicious that the pattern may be the result of volatile compounds from a source other than a flammable or combustible liquid. Even in evaporated samples, all the peaks in their known relative ratios should be present before an identification can be made.

One exception to the selective loss of compounds precluding identification has been reported by Mann and Gresham (1990). Flammable liquids recovered from soil samples were found to lack some of the diagnostic features associated with their standard chromatographic patterns. These missing features could not be attributed to chemical or physical processes. A review of the literature showed that crude oil is degraded in the environment by bacteria. Mann and Gresham were able to demonstrate that bacteria in soil show a preferential consumption of *n*-alkanes and least-substituted benzenes. The chromatographic patterns recovered from unsterile soil samples stored more than 6 days showed distinct differences from the original liquid. Soil samples should be analyzed immediately or frozen to prevent bacterial degradation of petroleum products.

Pyrolysis products from the sample matrix can interfere in the interpretation of chromatograms. A more selective detector, such as GC/MS, can be used to discriminate between compounds of petroleum product origin and pyrolysis products. Care must be taken in interpreting mass spectral data since pyrolysis products may include hydrocarbons. For example, the identification of a few compounds found in gasoline such a toluene, xylenes, and naphthalenes does not indicate the presence of gasoline. These compounds can be formed by burning synthetic materials. Longer columns providing increased resolution, or columns with a different stationary phase to alter elution order, can also be used to increase discrimination in pattern recognition.

GC/MS

The total ion chromatogram (TIC) for petroleum products is very similar to patterns obtained by GC-FID. For liquid samples or samples with little or no interference from the matrix, pattern recognition can be used to identify petroleum products analyzed by GC/MS. One advantage of GC/MS is that much more information is available from the collected data. For samples that show peaks not associated with a petroleum product, those compounds can be identified by their mass spectra and confirmed as likely being pyrolysis products. This is especially helpful to laboratories analyzing samples that have been collected using a canine. The laboratory can assist the handler in identifying the pyrolysis products which may be causing false alerts.

Table 3 **Checklist for Interpretation of Chromatograms**	
1	Obtain a chromatogram where the major peaks are "on-scale" (3/4 to full scale).
2	Note in what area of the chromatogram peaks are present. a. In what retention time range are peaks present, that is, light, medium, or heavy? In what n-alkane peak spread are peaks present? b. What is the width of the range, narrow or wide?
3	Once an area of interest is identified, look for characteristic features of a class of petroleum products. For example: a. Light petroleum distillate (C_4 - C_{11}) - May have a narrow boiling range. b. Medium petroleum distillate (C_8 - C_{12}) - 2 - 3 normal alkanes usually present. c. Gasoline (C_4 - C_{12}) - - Ethyl toluenes and 1,2,4-trimethylbenzene grouping present and all peaks in correct relative ratios. - C_4-alkylbenzenes present and in correct relative ratios. - Naphthalene and methylnaphthalenes usually present. d. Heavy petroleum distillate (C_9 - C_{23}) - - Homologous series of normal alkanes present. - Pristane and phytane present in diesel (No. 2) fuel oil. Use these features to limit your possibilities. Rule out some classes of petroleum products and focus on features of remaining possibilities. Patterns that do not fit into the above classes may belong to the variety of specialty products in the miscellaneous class. Check the patterns of known standards in these classes versus the unknown.
4	Compare the questioned chromatogram with a standard chromatogram. Line up the injection points. Match peaks in the standard to peaks in the questioned chromatogram for both retention time and relative ratios of peak height. **MAKE SURE BOTH STANDARD AND QUESTIONED SAMPLES ARE RUN UNDER THE SAME CHROMATOGRAPHIC CONDITIONS!**
5	Be able to explain differences between an unknown and standard based on evaporation, sample preparation technique, or (in soil samples) bacterial degradation. Unexplained differences should preclude an identification as an ignitable liquid.

Because of the complexity of petroleum products, it is generally not feasible to examine and identify each compound from its mass spectrum. Therefore, some method of extracting information that is characteristic of petroleum products is necessary. Smith (1983) reported a GC/MS data analysis method referred to as mass chromatography which identified classes of compounds characteristic of petroleum products. Smith used several characteristic ions for the major classes of compounds present in petroleum products to obtain extracted ion profiles (EIP). These EIP chromatograms of standards can be compared to unknowns using pattern recognition. Instead of one pattern (as in GC-FID) eight to ten patterns can be compared. Table 4 lists ions characteristic of compounds present in petroleum products. Figures 4, 5, and 6 show EIPs for alkanes, aromatics, and polynuclear aromatic compounds in gasoline.

Another approach to GC/MS data interpretation is based on the identification and quantitation of target compounds found in petroleum products (Keto and Wineman 1991; Lennard *et al.* 1995). Target compounds are qualitatively and semiqualitatively identified based on retention time and characteristic ions. The quantitative data are converted into a stick plot, termed a target compound chromatogram (TCC). The TCC shows the identity, relative abundance, and retention time of each targeted compound found in the sample; the TCC of the unknown is compared to standard TCCs. Interference from pyrolysis products is greatly reduced, thereby enhancing the ability to identify petroleum products (Keto 1995). Tables 5, 6, and 7 list the target compounds and ions used for the identification of gasoline, MPDs, and HPDs. Figure 7 shows the TIC and TCC of gasoline.

ASTM E1618-94 - *Standard Guide for Ignitable Liquid Residues in Extracts from Fire Debris Samples by Gas Chromatography/Mass Spectrometry* provides guidance for analysis of samples using both mass chromatography and target compound analysis. The guide states that while GC/MS is suitable for all types of samples, it is especially appropriate for samples containing high-background levels of coextracted materials from substrate or pyrolysis products. It also points out the method is suitable for single compounds and simple mixtures. The guide lists the specific types of compounds (alkanes, aromatics, and cycloalkanes) that are found in different classes of ignitable liquids offering guidance for the interpretation of data.

Table 4
Major Ions to Monitor in Fire Debris Analysis

Compound Type	m/e
Alkane	43, 57, 71, 85
Cycloalkane and Alkene	55, 69
n-Alkylcyclohexanes	82, 83
Aromatic - Alkylbenzenes Indanes	91, 105, 119; 92, 106, 120 117, 118; 131, 132
Alkylnaphthalenes	128, 142, 156, 170
Alkylstyrenes	104, 117, 118, 132, 146
Alkylanthracenes	178, 192, 206
Alkylbiphenyls/ Acenaphthenes	154, 168, 182, 196
Monoterpenes	93, 136
Ketones	43, 58, 72, 86
Alcohols	31, 45
MTBE (Methyl-*tert*-butyl ether)	59, 73

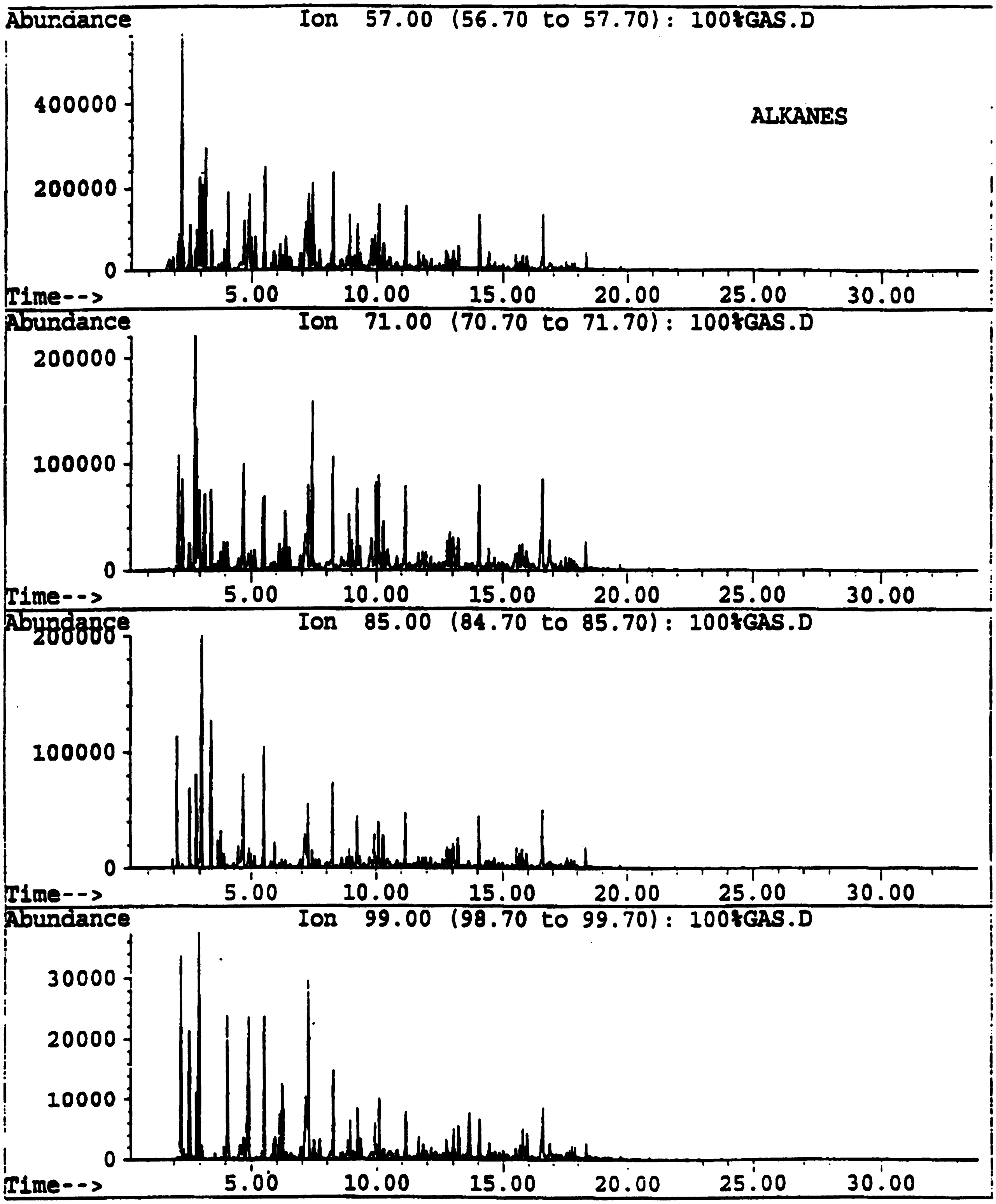


Figure 4. Extracted ion profile of alkanes in gasoline.

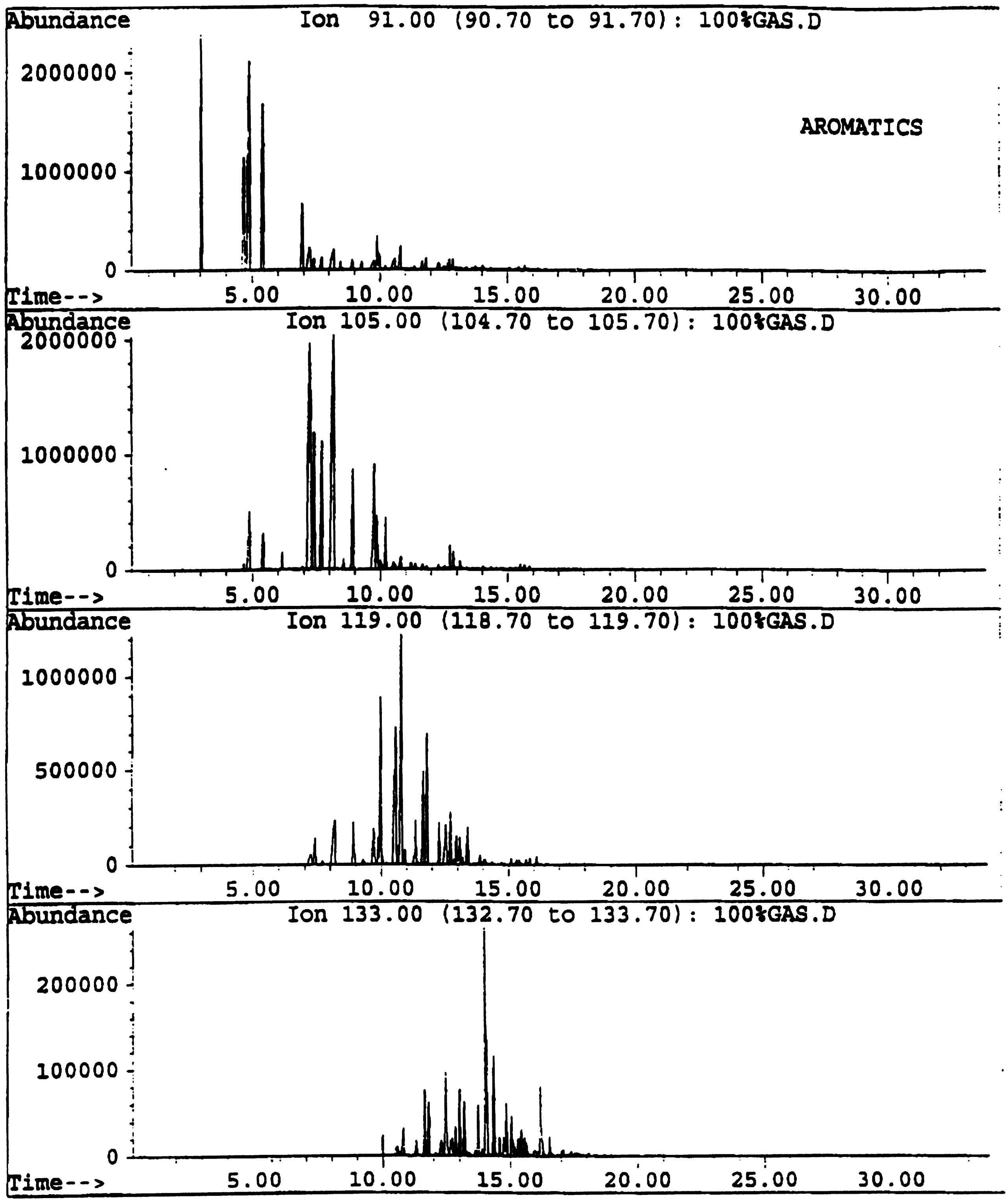


Figure 5. Extracted ion profile of aromatics in gasoline.

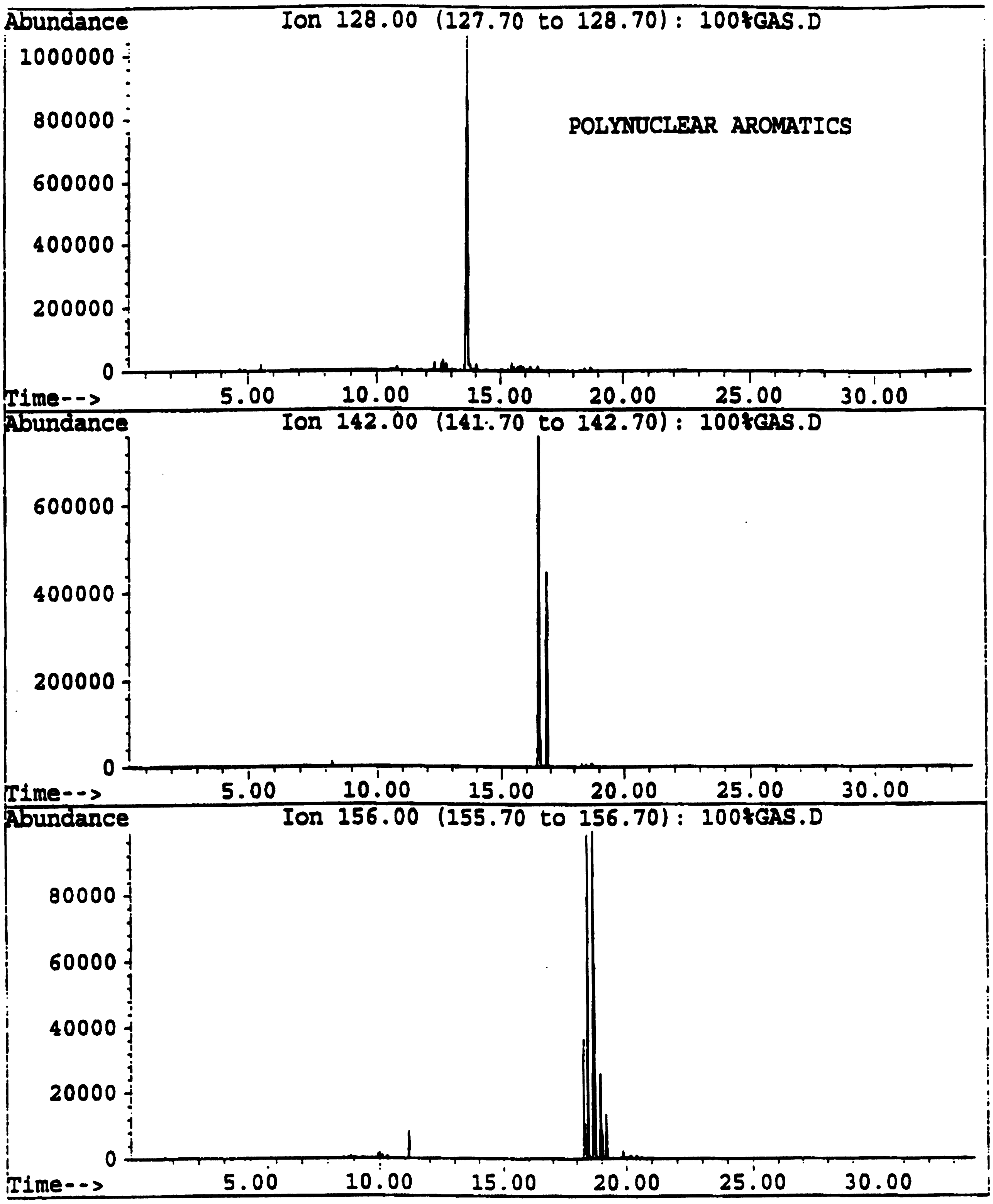


Figure 6. Extracted ion profile of polynuclear aromatics in gasoline.

Table 5 Gasoline Target Compounds		
Target Compound	Ion (m/e)	Relative Abundance
1,3,5-Trimethylbenzene	105 120	100 50
1,2,4-Trimethylbenzene	105 120	100 45
1,2,3-Trimethylbenzene	105 120	100 45
Indane	117 118 115	100 55 35
1,2,4,5-Tetramethylbenzene	119 134	100 50
1,2,3,5-Tetramethylbenzene	119 134	100 50
5-Methylindane	117 132	100 40
4-Methylindane	117 132	100 40
Dodecane	57 71 85	100 65 50
4,7-Dimethylindane	131 146	100 40
2-Methylnaphthalene	142 141	100 80
1-Methylnapthalene	142 141	100 85
Ethylnaphthalenes (Mixed)	141	100
1,3-Dimethylnaphthalene	156 141	100 90
2,3-Dimethylnaphthalene	156 141	100 90

Table 6 MPD Target Compounds		
Target Compound	Ion (m/e)	Relative Abundance
Nonane	57 85 71	100 50 35
Propylcyclohexane	83	100
1,3,5-Trimethylbenzene	105 120	100 50
1,2,4-Trimethylbenzene	105 120	100 45
Decane	57 71 85	100 40 30
1,2,3-Trimethylbenzene	105 120	100 45
n-Butylcyclohexane	83 82	100 70
trans-Decalin	138 96 81	100 65 55
Undecane	57 71 85	100 55 35
1,2,3,5-Tetramethylbenzene	119 134	100 50
n-Pentylcyclohexane	83 82 55	100 80 70
Dodecane	57 71 85	100 65 50
n-Hexylcyclohexane	83 82 55	100 80 60

Table 7
HPD Target Compounds

Target Compound	Ion (m/e)	Relative Abundance	Target Compound	Ion (m/e)	Relative Abundance
Decane	57 71 85	100 40 30	Tetradecane	57 71 85	100 65 50
n-Butylcyclohexane	83 82	100 70	n-Octylcyclohexane	83 82	100 90
trans-Decalin	138 96 81	100 65 55	2,3,5-Trimethylnaphthalene	170	100
Undecane	57 71 85	100 55 35	Pentadecane	57 71 85	100 70 50
1,2,3,5-Tetramethylbenzene	119 134	100 50	n-Nonylcyclohexane	83 82	100 80
n-Pentylcyclohexane	83 82 55	100 80 70	Hexadecane	57 71 85	100 70 50
Dodecane	57 71 85	100 65 50	Heptadecane	57 71 85	100 80 50
n-Hexylcyclohexane	83 82 55	100 80 60	Pristane (2,6,10,14-Tetramethylpentadecane)	57 71 85	100 80 40
2-Methylnaphthalene	142 141	100 80	Octadecane	57 71 85	100 80 55
1-Methylnaphthalene	142 141	100 85	Phytane (2,6,10,14-Tetramethylhexadecane)	57 71 85	100 75 60
Tridecane	57 71 85	100 65 40	Nonadecane	57 71 85	100 75 60
n-Heptylcyclohexane	83 82	100 85	Eicosane	57 71 85	100 80 55
1,3-Dimethylnaphthalene	156 141	100 90	Heneicosane	57 71 85	100 80 55

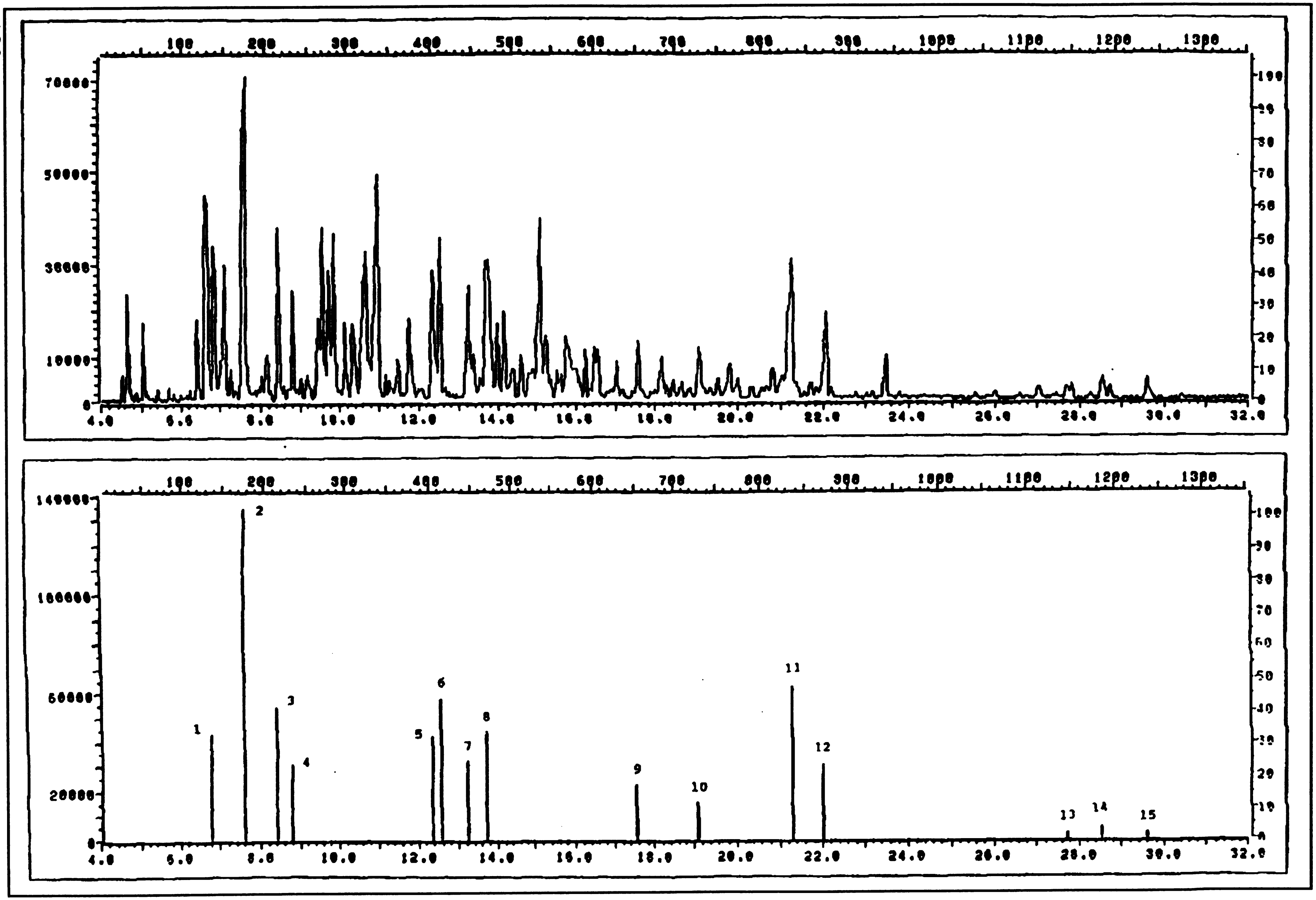


Figure 7. Total Ion Chromatogram (top) and Target Compound Chromatogram (bottom) of gasoline.

SAMPLE PREPARATION

A variety of methods are available to recover flammable and combustible liquids from fire debris samples. Each method has its advantages and disadvantages. While adsorption on charcoal is the most widely used recovery method in the United States, analysts should be familiar with and know when to use other methods of recovery. No single method can be universally applied to all types of petroleum products and samples (Bertsch and Zhang 1990). The ideal recovery technique would be simple, effective, and rapid. The sample matrix should be taken into consideration when choosing a method. The analyst must be aware of the effects of the sample preparation technique on the final chromatogram obtained to properly interpret the results. A review of sample preparation techniques for identification of petroleum products reported that improved isolation techniques resulted in improved sensitivity and specificity of product identification (Caddy *et al.* 1991).

Liquid samples require virtually no sample preparation; they can be injected neat using a wet needle or diluted with an appropriate solvent. Some liquid samples submitted for analysis are mostly water; liquid samples should be checked for ignitability and miscibility. If they have no odor and cannot be ignited, they are most likely water. Immiscibility with a nonpolar solvent (such as carbon disulfide) gives an additional indication that the sample is water.

Distillation

Distillation techniques were among the first used to isolate petroleum products from debris samples. Distillation techniques include simple distillation, steam distillation, and vacuum distillation (Brackett 1955). Steam distillation techniques have been modified by the addition of alcohol (Macoun 1952) and ethylene glycol (Brackett 1955). Simple distillation is suitable when only low-boiling products are present. Yip and Clair (1976) concluded that steam distillation was useful for recovering petroleum products if previous headspace sampling gave negative results. Hrynchuk *et al.* (1977) reported using vacuum distillation to recover petroleum products from debris. Levels of 50 ppm by weight were routinely recovered. One cited advantage of the preparation method was that the exhibit substrate was essentially unchanged. Preservation of the substrate can be of importance when examining documents and device components.

ASTM E1385-90 - *Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Steam Distillation* outlines current procedures for separating visible quantities of water-insoluble hydrocarbons from fire debris. The standard recommends that the technique be used only for samples which have a detectable odor of petroleum product at room temperature. One advantage cited for the technique is that the distilled liquid can be used as a courtroom exhibit, the odor being readily recognizable by a jury.

Distillation techniques are not used at the ATF Laboratories because they are time consuming and lack sensitivity. These types of samples can be more efficiently processed using other sample preparation techniques. However, it is important that analysts are aware of distillation techniques and understand the theory of how they work.

Static Headspace

The vapor pressures of liquids are a function of their chemical composition. In a closed system a liquid is in equilibrium with its vapor. As a result, any flammable or combustible liquid present in the fire debris will vaporize and be present in the headspace of the sample container. A small amount of this headspace can be sampled and injected into a GC to detect the presence of such a product. Heating the sample in its original container will increase the vapor pressure and, thus, the concentration of vapors from the liquid in the headspace of the samples. Headspace sampling is simple and rapid (Loscalzo *et al.* 1977), but lacks sensitivity.

ASTM E1386-90 - *Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Solvent Extraction* outlines the procedure for removing small quantities of flammable or combustible liquid vapors from the headspace of debris containers. The practice calls for heating the sample (preferably in its original container) prior to sampling and analysis by GC. The technique is useful for screening samples for the presence of a particular type of petroleum product, and is also useful when volatile oxygenated products (such as alcohols or lacquer thinners) are suspected. The practice is one of the least sensitive sample preparation methods, however, and may not detect quantities of less than 5 µl to 10 µl of a petroleum product in an empty gallon can (Brettel *et al.* 1984).

Some analysts use headspace to screen samples at room temperature. Others heat the samples to temperatures from 50°C to 120°C to increase vapor pressure and, thus, the concentration of vapors from liquids in the debris into the headspace (Yip and Clair 1976). This screening ensures that any volatile oxygenated products (such as alcohols and lacquer thinners) present in sufficient quantity, are recovered. Oxygenated compounds are difficult to recover using adsorption/elution techniques. Often these compounds elute with the solvent front in a typical GC program used for fire debris analysis. Samples are typically heated in an oven or on a hot plate from 10 minutes to 30 minutes. Heating wet samples above 100°C may cause venting or rupturing of the container and loss of the sample. Another danger from overheating is charring the contents and producing additional pyrolysis products. The ATF standard approach calls for heating cans in an oven at 80°C for 20 minutes to 30 minutes. A small hole is punched in the lid of the container prior to heating and covered with tape or plugged with a rubber septum. Using a heated vapor-tight syringe (glass or disposable), a small sample (0.5 cm^3 to 5 cm^3) of vapor is taken from the container and injected directly into the GC. The syringe can be heated by placing it over the FID detector on the GC. Heating the syringe prevents vapors from condensing in the syringe prior to injection. The quality of vapor injected depends on the type of column. Capillary columns (even when using high split ratios) do not give efficient separations when more than 1 cm^3 of vapor is injected.

Chromatograms of vapors from flammable and combustible liquids can differ considerably from liquid sample chromatograms. The most volatile compounds of the liquid residue will predominate in the headspace and, therefore, the chromatographic pattern. The headspace pattern of a fresh sample of gasoline will be dominated by the most volatile components and little of the characteristic heavier components will be observed. This swamping of the headspace by the most volatile components is most pronounced when large amounts of flammable liquid are present in the container. A library of standard chromatograms prepared by headspace analysis should be developed if this technique is used for identification.

Dynamic Headspace Adsorption

While static headspace techniques are simple and rapid, they lack sensitivity. Distillation recovery techniques are time consuming and cumbersome. In searching for a rapid and sensitive sample preparation method, forensic scientists borrowed from the industrial hygiene industry and began using vapor concentration techniques using sorption materials.

Chrostowski and Holmes (1979) reported a procedure for the collection and concentration of vapors from fire debris samples on activated charcoal. Over the years we have modified the originally-published parameters. ASTM E1412-91 - *Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Dynamic Headspace Concentration* provides general guidelines on the use of charcoal tubes to recover liquid residues from samples. The ATF standard approach calls for using a vacuum to pull vapors from a container heated to 90°C and passing the vapors over a tube of activated charcoal. An airflow rate of 300 ± 100 ml/min is recommended. A second charcoal tube is placed in the container lid to filter air entering the container. Once a temperature of 90°C is reached, sampling is continued for another 5 minutes. Care should be taken to avoid heating above 100°C to avoid additional pyrolysis of the sample.

The advantages of dynamic adsorption are that it is efficient (essentially sampling all the headspace) and, therefore, sensitive. It is also rapid; samples can be prepared for analysis in less than 1 hour. It can be used for a wide range of petroleum products from light petroleum distillates to heavy petroleum distillates. Disadvantages include essentially complete extraction if small amounts of residues are present; this would preclude retesting by another laboratory. Another disadvantage is the failure to recover the heavy ends of diesel fuel in some samples. It is often not possible to differentiate between a kerosene (Class 4) and diesel fuel (Class 5) product using any headspace technique. This is illustrated in Figure 8; note that the highest boiling alkane recovered is C_{18}. The liquid diesel used to prepare this sample contains normal alkanes out to C_{23}. While this sample was prepared using passive headspace sampling, similar results are obtained using dynamic headspace sampling. Usually, solvent extraction is necessary to distinguish between Class 4 and Class 5 products.

Analysts should be aware of some slight differences in chromatographic patterns between neat liquids and samples eluted from charcoal. These differences come from preferential adsorption and desorption of compounds, particularly with samples containing large amounts of residue. Aromatic compounds will displace aliphatic and high molecular weight compounds will displace lower molecular weight compounds. Normally these differences are minor and there is no need to run a separate library of standards prepared by an adsorption/elution method.

Passive Headspace Adsorption

An alternative method of collection of vapors onto sorption media is passive sampling (that is, placing the sorption media in the sample headspace). After waiting some period of time, the sorption media is removed and compounds desorbed for analysis. This type of sample preparation is attractive because it involves very little time and labor.

Twibell and Home (1977) demonstrated that activated charcoal in contact with headspace of debris for several hours adsorbed sufficient vapors for pyrolysis/GC analysis. Juhala (1982) reported success using both carbon-coated wires and carbon-coated Plexiglass® beads with desorption with carbon disulfide. Dietz (1991) reported success using commercially available, carbon-coated Teflon™ strips marketed for use in environmental monitoring badges. As little as 0.2 µl of an equal mixture of gasoline, kerosene, and diesel fuel was recovered using the charcoal strips.

ASTM E1413-91 - *Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Passive Headspace Concentration* offers the analyst a practical guide for using this sample preparation technique. Advantages of the technique are that it is simple, recovers most petroleum products, and is sensitive. A disadvantage is overnight analysis time for weak samples. Also, as in dynamic headspace sampling, compounds above C_{18} are not always recovered from debris samples. Again, this precludes distinguishing between Class 4 and Class 5 products (see Figure 8).

The ASTM E1413-91 practice does not specify the quantity of charcoal to use in sampling. Because of the large capacity of charcoal, a piece of commercially available strip 3/8" round is sufficient for most samples. As with other charcoal adsorption methods, analysts must be aware of charcoal's preferential adsorption of different classes of compounds. For samples having no detectable odor and, therefore, containing at most trace amounts of petroleum products, this preferential adsorption is not a concern. There are sufficient adsorption sites available for all types of compounds. However, samples having a strong odor indicating large amounts of petroleum product should be sampled so that preferential adsorption does not occur. In passive sampling, this can significantly alter the chromatographic profile and make interpretation difficult. For samples with little or no odor, after placing the charcoal in the container, the samples are heated for about 16 hours at between 60°C and 90°C. Using a higher temperature helps recovery of higher-boiling compounds, but also can contribute to background interference by generating and recovering additional pyrolysis products. For samples with a noticeable odor, sampling at ambient temperature for 1 hour to 4 hours is generally sufficient to recover enough product to produce an identifiable chromatogram.

After sampling, the charcoal is eluted with a small amount of solvent (8 drops to 20 drops) and analyzed. Carbon disulfide is the best solvent for desorbing hydrocarbons from charcoal. Some analysts prefer not to use carbon disulfide because of its toxicity. Diethyl ether can be used to elute the charcoal, but with a loss of about 10% efficiency in desorbing hydrocarbons.

Solvent Extraction

Solvent extraction has been used to recover petroleum products from debris longer than GC has been used as a method for separation and identification of recovered products. Ettling (1963) reported using dichloromethane to extract petroleum products from fire debris with analysis by infrared spectroscopy. Solvent extraction continued to find use as an isolation technique for GC analysis (Ettling and Adams 1968; Midkiff 1978). Midkiff reported that a variety of solvents were being used including *n*-pentane, hexane, dodecane, hexadecane, methylene chloride, chloroform, carbon tetrachloride, benzene, ethyl ether, and carbon disulfide. The technique is based on the solubility of hydrocarbons found in ignitable liquids in the solvent. Debris samples are typically soaked in a suitable solvent for up to 20 minutes and the solvent is decanted, filtered, and evaporated into a small volume to concentrate any isolated product prior to analysis.

An advantage of solvent extraction is the recovery of nonvolatile materials not recovered by vapor sampling techniques. Compounds less volatile than C_{18} are difficult to recover from burned debris samples by heated headspace or adsorption techniques, which depend on the volatility of the compounds and their presence in the headspace. Therefore, it is not always possible to distinguish between kerosene (which typically ends around C_{17}) and diesel fuel (which extends to C_{23}). In such cases, solvent extraction is necessary to distinguish between kerosene and diesel fuel products. Because solvent extraction is not as sensitive as adsorption/elution concentration techniques, solvent extraction of samples containing small amounts of a heavy petroleum distillate previously recovered using

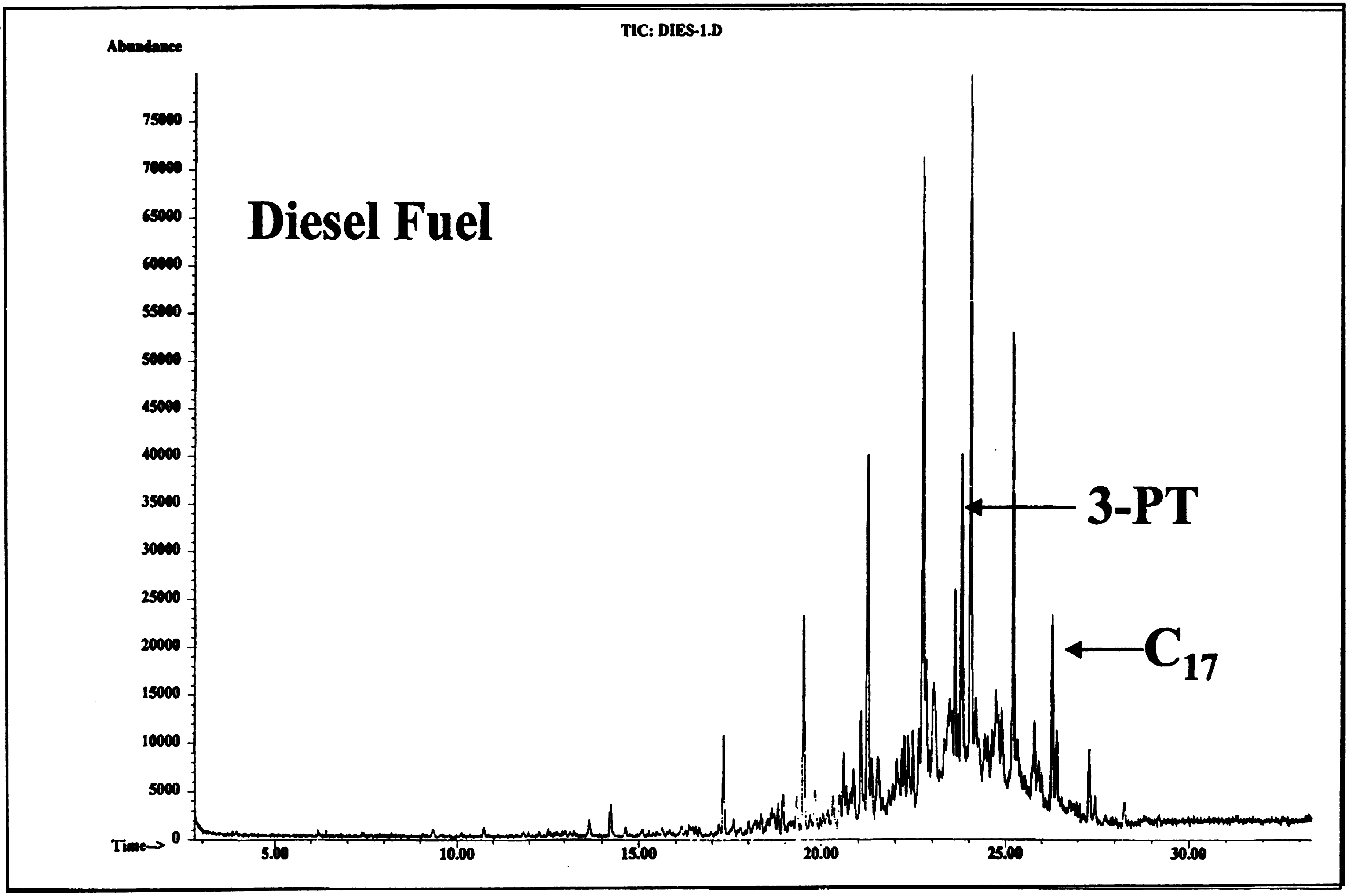


Figure 8. Diesel fuel recovered from carpet by passive headspace sampling with 3-phenyltoluene added to monitor extraction efficiency.

passive or dynamic headspace may give a negative result. In these cases, the possibility of either a Class 4 or Class 5 product should be reported. Solvent extraction is also useful for recovering nonvolatile products such as lubricating oils and waxes.

A disadvantage of solvent extraction is that substrate and pyrolysis products are generally soluble in commonly-used solvents and will be coextracted with any petroleum product in the sample. As a result, the sample matrix should be evaluated prior to extraction. The presence of these substrate and pyrolysis products complicates chromatogram interpretation. High molecular weight products may also foul injection ports and columns. While the practice is useful for all classes of petroleum products, it is least applicable to light petroleum distillates which may be lost when concentrating the solvent by evaporation. In addition to the toxicity and costs of solvents, the technique is time consuming, labor intensive, and less sensitive than both dynamic or passive headspace sampling.

ASTM E1386-90 - *Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues from Fire Debris Samples by Solvent Extraction* provides practical guidelines for using solvent extraction to isolate ignitable liquids. It is difficult to recover the solvent from porous materials such as wood or carpet, but it is a quick and easy method for isolating ignitable liquids from nonporous surfaces. A common example is the analysis of a Molotov cocktail; rinsing the glass with a small amount of solvent is more efficient than using a headspace technique.

Analysis Scheme for Analyzing Fire Debris

Because no one technique is ideal for every sample, the analyst should be familiar with the advantages and disadvantages of each sample preparation technique. The sample substrate and the type and quantity of petroleum product that may be present in the debris must all be considered when deciding how to proceed with the sample preparation. Based on advantages and disadvantages, various analysis schemes involving some or all of the methods can be constructed. Willson (1977) proposed a systematic analysis scheme starting with recovery of the sample to identification of a petroleum product.

Figure 9 shows an analysis scheme using the more commonly employed sample preparation techniques. The first step involves opening the can to inspect the sample and note any obvious odors. Because of the toxic properties of some fire debris samples, care should be exercised in not exposing oneself directly to the vapors. Because containers are opened for a limited amount of time, there is no loss of significant amounts of petroleum product vapor in the headspace. Examining the debris gives the analyst some indication of what kinds of substrate and pyrolysis products may also be recovered. It also avoids problems such as the evidence being double packaged or evidence containing large quantities of liquid petroleum product (which, on heating, could lead to disastrous results). Based on sample matrix and detectable odors, a sample preparation method is chosen. The analysis scheme shows the logic flow that can be applied to most samples.

DOCUMENTATION REQUIREMENTS

A laboratory case jacket containing all notes, data, and paperwork associated with a submitted case is maintained in the laboratory. The case jacket must contain the following:

- Paperwork from submitting agent requesting analysis.
- Chromatograms generated for each sample.
- Chromatograms of standards used for identification.
- A summary sheet listing exhibit number, how it was packaged, what the package contained, sample preparation technique used, and results.
- Any additional notes generated in analysis.

PRESERVATION OF SAMPLES

Because fire debris samples are not homogeneous, splitting samples prior to analysis is not an option. As a result, the analyst should take care to preserve samples so they can be retested if necessary. Extracts from the samples can be preserved on charcoal. The following procedures were developed by Richard E. Tontarski, Jr., and Richard A. Strobel of the ATF Forensic Science Laboratory.

Dynamic Headspace Concentration

The eluent from the charcoal tube can be preserved after analysis by placing a small amount of activated charcoal (approximately 1 gram) in the vial. Allow the solvent to evaporate; hydrocarbons in the

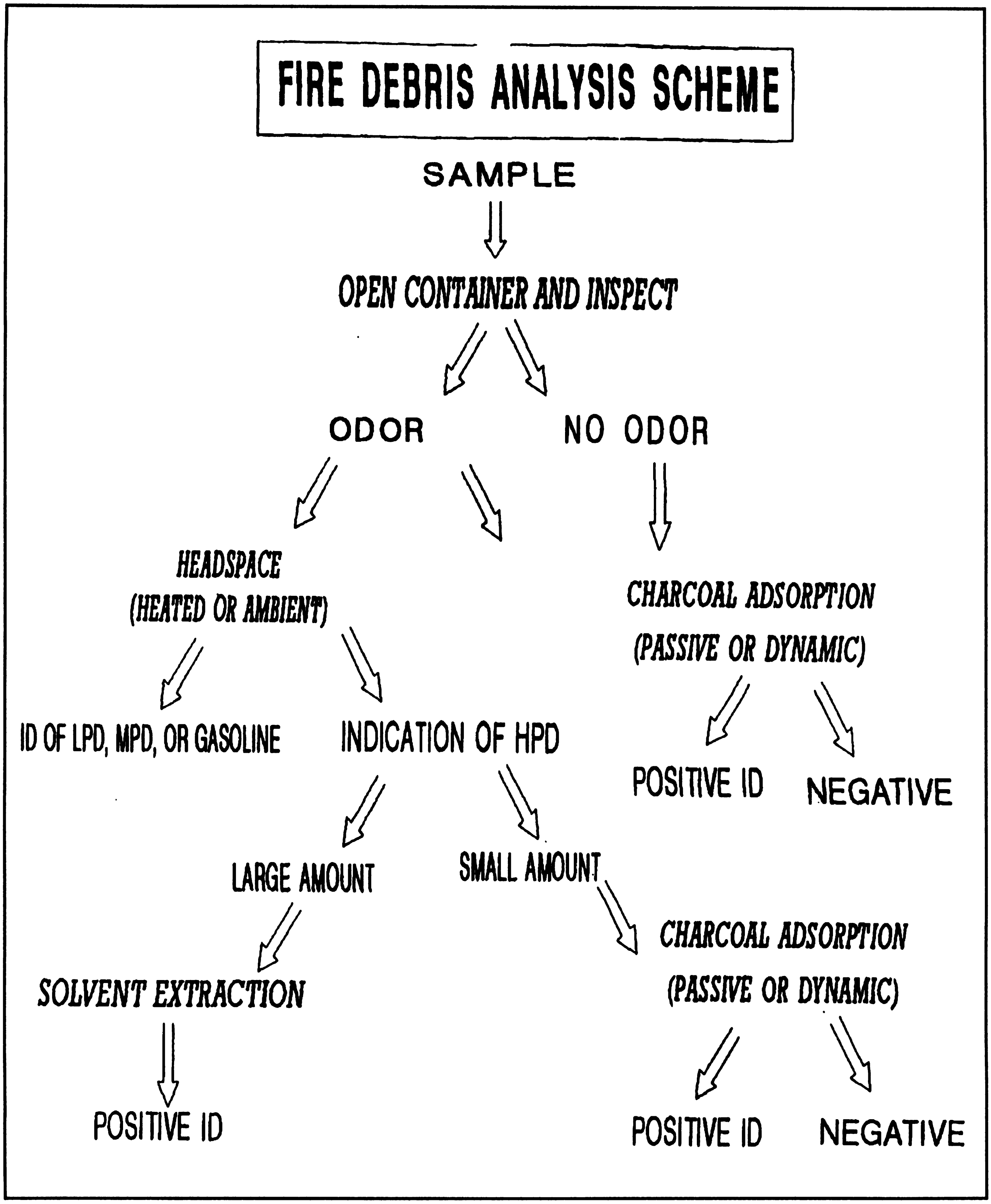


Figure 9. Flowchart for analysis of fire debris samples.

solvent will be adsorbed onto the charcoal. Alternatively, a piece of commercially available charcoal strip can be placed in the vial with the eluent and the solvent allowed to evaporate.

Solvent Extraction

Use the same procedure as outlined under dynamic headspace concentration.

Passive Headspace Concentration

After analysis, allow the solvent to evaporate in the vial containing the original charcoal strip used for extraction. Alternatively, use two charcoal strips when sampling. Preserve one strip in a vial and use the other for analysis.

REPORT WORDING

The ATF Standard Approach to Fire Debris Analysis also includes guidance on report wording. The basic question normally asked by the investigator is: "Are there any ignitable liquids in the sample?" The laboratory report should clearly and succinctly answer this question. When a sample's chromatogram displays all the features which the analyst deems necessary for a particular class identification, the report will state that a petroleum product (not an accelerant) of that class was found and will list examples. Accelerant means any material used to aid the spread of the fire. Materials other than ignitable liquids can be used to intentionally spread a fire and be properly termed accelerants. Conversely, finding a petroleum product in a sample does not mean it was used as an accelerant. The petroleum product may be inherent to the fire scene, such as a sample that contains a medium petroleum distillate or kerosene product that was used as a carrier for an insecticide spray.

For classes other than automotive gasoline, it is important to list examples of the classes. Most fire investigators and the general public do not know that one class of product may have a variety of commercial end uses. The refinery may sell a particular medium petroleum distillate which is then sold for a variety of end uses (such as paint thinner, mineral spirits, charcoal starter fluid, dry cleaning solvent, and insecticide spray carrier). Not listing examples (or only listing one example) can mislead the investigator in what type of product he is trying to determine was used.

Vague and misleading wording should never be used. Some examples include: "hydrocarbons in the range of gasoline were found," "benzene, toluene, and xylenes (components of gasoline) were identified," and "hydrocarbons from an unknown source were detected." Such wording does not answer the question originally posed by the investigator and can lead to misinterpretation and misrepresentation of the results. If no class of ignitable liquid can be identified, the report should state that no ignitable liquids were detected or identified.

QUALITY ASSURANCE PROCEDURES

ATF arson laboratories have progressed well beyond what was standard practice 7 years ago. This is, in part, due to the increasing emphasis placed on quality control by such outside forces as courtroom challenges to expert testimony and by the accrediting/reaccrediting requirements of the American Society of Crime Laboratory Directors (ASCLD). There has also been a recognition among our examiners that proper quality control (although initially time consuming) pays for itself by greater examiner confidence in results, instrumentation, and improved early warnings of equipment malfunctions.

System Blanks

The 1988 *ATF Standard Approach to the Detection of Petroleum-Based Accelerants* specified checking all items that could come in contact with the evidence for contaminants, that is, a system blank. Our revised standard approach continues to use the system blanks for documenting interference checks. The system blank should use all the materials used in the laboratory for recovering vapors from a sample. The blank depends on the sample preparation method used. In headspace sampling, the blank should be air taken with a clean syringe that later can be used for sampling vapors. In sampling using sorption/elution, charcoal tubes or strips prepared in the same manner as samples should be eluted with carbon disulfide using the same volumes and apparatus. In solvent extraction, the solvent used is the blank; it should be evaporated to the same extent as the sample. Typically, no control samples of the can or other packaging are provided. These materials are also part of the system and a potential source of contamination. Investigators are encouraged to submit samples of containers from new lots they purchase to be checked for possible contamination.

Instrument Performance

The ATF standard recommends documenting instrument performance using known ignitable liquids. A mixture of gasoline, kerosene, and diesel

fuel covers the entire boiling point range of ignitable liquids encountered in fire debris analysis. This mixture can be used to establish a chromatographic program that gives sufficient resolution when first developing a method. Once a method is established, both sensitivity and resolution can be checked by comparing a known concentration standard against previously run data. Dramatic changes in retention time indicate a problem with the column or carrier gas flow rate. Decrease in peak height may signal a problem with the detector. Alternately, the test mixture is described in ASTM E1387-90 - *Standard Test Method for Flammable or Combustible Liquid Residues in Extracts from Samples of Fire Debris by Gas Chromatography.* Figure 1 is a chromatogram of the instrument test mixture which was prepared in our laboratory using 2 mg/ml of each of the components. The test mixture consists of the even-numbered alkanes n-hexane through n-eicosane and the aromatic hydrocarbons, toluene, p-xylene, o-ethyltoluene, p-ethyltoluene, and 1,2,4-trimethylbenzene.

We have maintained quality control charts based on the data obtained from the test mixture for a 1-year period. The use of control charts to document instrument performance is strongly recommended. The control charts measure the response over time of an early eluting aromatic compound, toluene, and a late eluting *n*-alkane (eicosane). A third control chart records the total peak area of the test mixture to monitor changes in the overall detector response. The Appendix contains detailed instructions on maintaining control charts using the ASTM test mixture.

Extraction Efficiency Check

A method to check the extraction efficiency of dynamic and passive headspace sample preparation methods was developed by Randall Riddell of the Georgia Bureau of Investigation Division of Forensic Sciences. The procedure monitors extraction efficiency by adding a known compound to the sample matrix. Recovery of the added compound assures that sampling conditions were sufficient to recover any ignitable liquids in the sample. Desirable characteristics of such a compound are: 1) it does not interfere with chromatographic interpretation; 2) it is not a normal constituent of petroleum products; and 3) it is a good indicator of extraction efficiency. Figure 3 shows a chromatogram of diesel fuel recovered using passive headspace sampling to which 1 µl of 3-phenyltoluene (3-methyl biphenyl) was added prior to sampling. This compound is not a constituent of ignitable liquids. Being a single peak, it does not interfere with chromatogram interpretation. Eluting between tetradecane and hexadecane, 3-phenyltoluene is also a good indicator of extraction of the higher molecular weight compounds. Figure 10 shows a chromatogram of a trace amount of diesel fuel recovered from a burned carpet. The large 3-phenyltoluene peak shows that good extraction efficiency was obtained, thus assuring that the small peaks from the diesel fuel are from a low concentration (not poor extraction conditions). Other similar compounds that can be used include 2-phenyltoluene, 4-phenyltoluene, and 2-fluorobiphenyl.

PROFICIENCY TESTING PROTOCOL

Proficiency testing is an important part of the laboratory's quality assurance effort. Both the ASCLD and the American Board of Criminalistics (ABC) require annual proficiency testing in order to maintain accreditation and certification, respectively. The following proficiency testing guidelines are adopted from the ABC's policy manual.

Each examiner must successfully complete a proficiency test once a year in each area of expertise in which they do casework. Laboratories are encouraged to appoint a Proficiency Testing Coordinator whose responsibility is to oversee the administration of proficiency testing within the laboratory.

General Requirements

Proficiency tests are to be prepared by a laboratory, group of laboratories, regional association, or professional testing agency other than the participant's own laboratory. Proficiency tests can be open or blind as long as they conform to outlined standards.

The Proficiency Testing Coordinator should notify participants in writing of the results (successful or unsuccessful). In the event of an unsuccessful test result, corrective action is needed. The reason for the unsuccessful result should be documented as well as steps taken to ensure future performance is successful. The examiner should take another external proficiency test within 6 months.

Test manufacturers must maintain a list of participants who have completed proficiency tests along with the date of their testing, the specialty areas tested, and the answers submitted. The participant is responsible for maintaining all notes, worksheets, and other documentation used to develop conclusions. The ABC requires that these records along with the

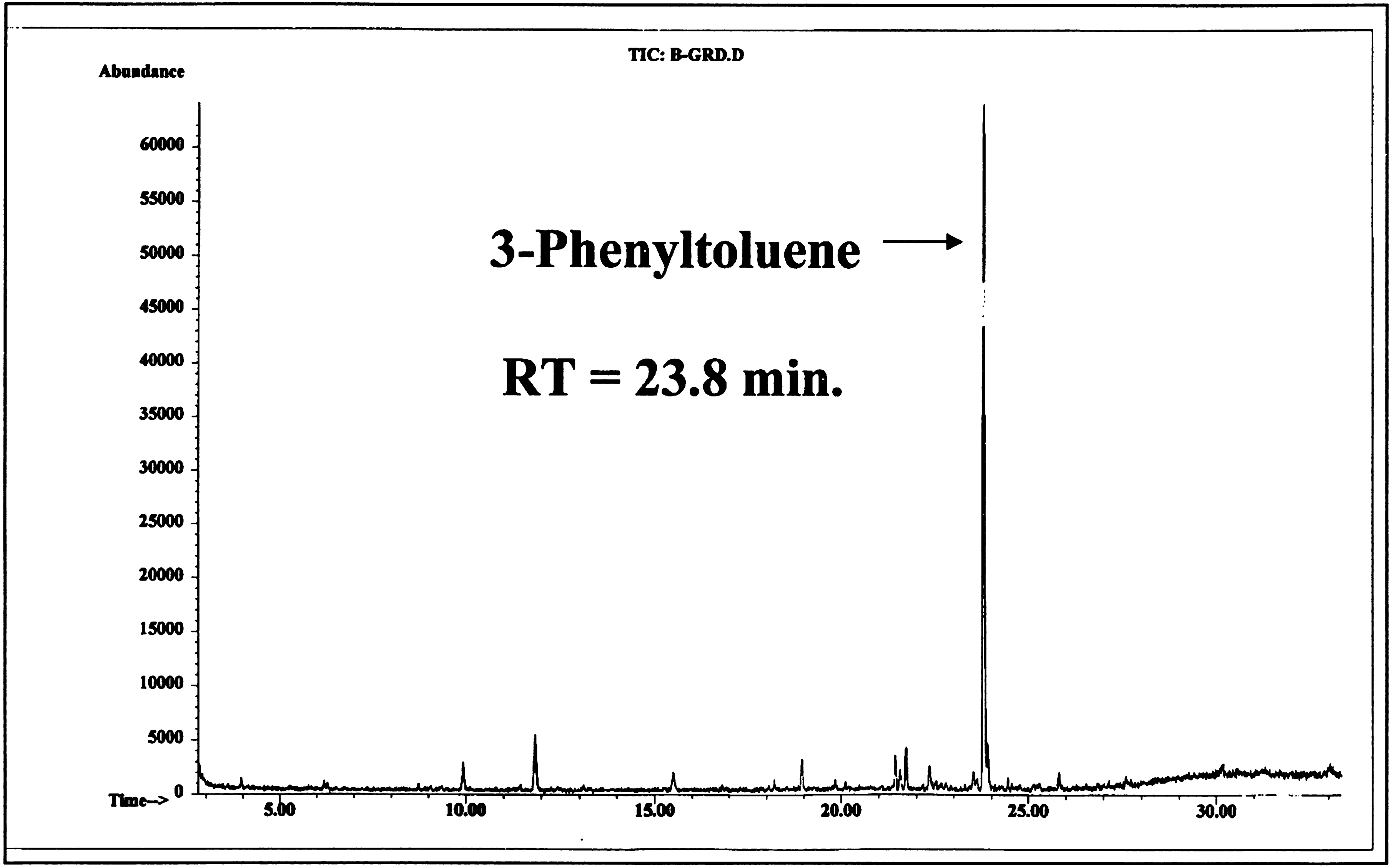


Figure 10. Trace amount of diesel fuel recovered by passive headspace sampling with 3-phenyltoluene added to monitor extraction efficiency.

analytical data be available for ABC review for a period of 5 years after a given test.

Specific Requirements for Fire Debris Analysis

Fire debris proficiency samples should test a participant's ability to recover ignitible liquid residues from fire debris, interpret chromatographic patterns, and document analytical procedures. Tests should be designed to demonstrate the participant's ability to recover and identify flammable/combustible liquid residues using the methods routinely employed in the laboratory. Sample types should include those routinely encountered in casework (such as liquid samples, empty containers, concentrated samples, very diluted samples, and negative samples). Interpretation skills should include the ability to distinguish pyrolysis patterns from petroleum product patterns and the ability to classify petroleum products according to the ASTM E1387-90 classification scheme. The types of ignitible liquids used in tests should be readily available and commonly encountered in casework. Obscure products not readily available or specialty products should not be used. Tests should be designed so that the participant's ability to recognize products in various stages of evaporation is tested. Documentation must include notes regarding sample handling, extraction and preparation, instrument charts, graphs and other data, and standard and control sample results.

Suitable types of proficiency tests are blind testing, re-examinations, commercially manufactured tests, and samples prepared by someone outside the participant's laboratory. An effort should be made not to run the same types of tests each year. For example, one test may be designed to demonstrate proficiency in sample preparation, but this ability need not be tested each year. Simulated debris samples should include matrices commonly encountered in fire debris analysis (such as wood, carpet, tile, cloth, shoes, and plastics). It is desirable to have several samples in one test (some with and some without petroleum products) providing scenario similar to casework. A reasonable number of manufactured samples should be tested by a referee laboratory to determine that the samples were correctly prepared.

Successful Completion Criteria

Successful completion is defined as an analysis which meets the test provider's specifications with no false inclusions or exclusions. Levels of discrepancies between a participant's results and the manufacturer's specifications can be put into three classes. A Class 1 discrepancy raises immediate concern regarding the quality of the laboratory work product. For example, a false inclusion or exclusion is reported. An example of a false inclusion is an identification when no petroleum product was present. This may be the result of incorrect interpretation of pyrolysis products or contamination of the test sample in the laboratory.

A Class 2 discrepancy is a problem which may affect the quality of the work, but is not persistent or serious enough to cause immediate concern for the overall quality of the participant's work product. An example of a Class 2 discrepancy is inconclusive results from a sample from which a majority of participants reported a correct positive result. Class 2 discrepancies may be judged as failures depending on the nature and severity of the reasons for failing to reach a correct result. In general, Class 2 discrepancies that are due to the inability to identify commonly encountered petroleum products or equivocal results due to an inability to properly perform analytical tests will be judged as failures. Class 2 discrepancies which are due to partial analyses or lack of methodology or technology for low levels or single component flammables may be judged as nonparticipation.

A Class 3 discrepancy is determined to have minimal effect or significance, is unlikely to recur, is not systematic, and does not significantly affect the fundamental reliability of the participant's work. Examples are unclear report wording, wording not conforming to industry practice, and clerical errors.

SUMMARY

As the legal and forensic communities become increasingly aware of these standards, analysts should be familiar with their contents. While the standards are written to be broad enough to allow variation, some laboratories may have a basis for doing something differently from prescribed methods described in the standards. The laboratory and analyst should be able to support this difference and explain how it does not affect the quality of their conclusions. For example, in the area of report wording ATF Laboratories have an internal standard for report wording and the format that does not conform exactly with ASTM E1387-90. This difference does not affect the quality of the results and is not significant.

This paper provides a background on the advances in fire debris analysis which provide the foundation for a current protocol for analyzing fire debris. A general outline on components of a standard protocol is offered for guidance in developing standard methods. Protocols should include quality

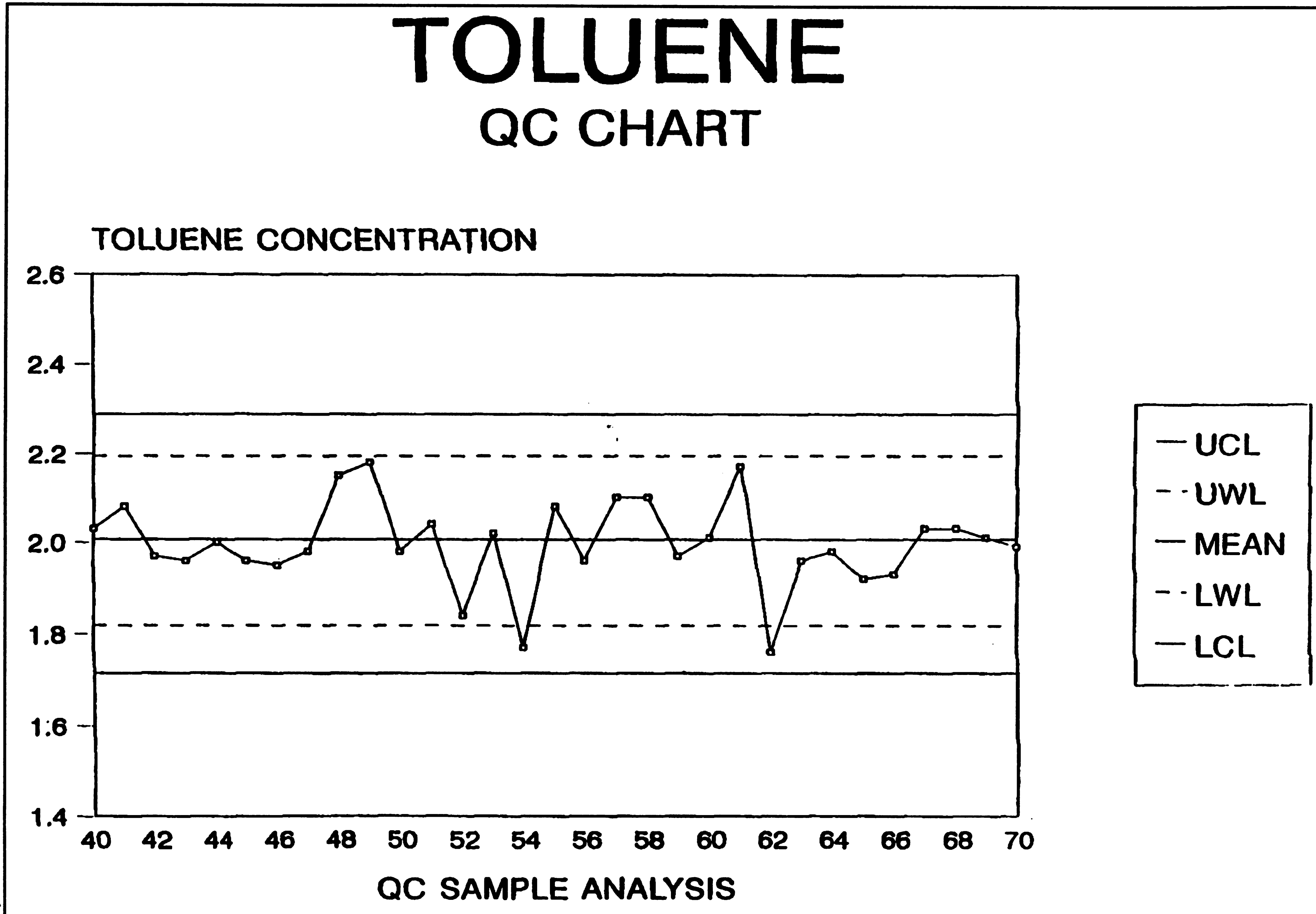


Figure 11. Quality control chart of toluene.

assurance procedures, methods for sample preparation and instrumental analysis, interpretation guidelines, and documentation requirements. ASTM practices, test methods, and guides provide a good basis for developing a standard protocol.

ACKNOWLEDGMENTS

The authors wish to thank Patricia M. Pannuto and Richard E. Tontarski, Jr., for their thoughtful comments in the preparation of this paper.

APPENDIX

Instructions for Preparing a Quality Control (QC) Chart

To collect data for establishing the control chart, an internal standard method of analysis is used. Dodecane in the test mixture is suitable for the internal standard compound because it is in the middle of the chromatogram. The quality control limits were calculated after collecting 20 data points over a period of time when the instrument is considered to be operating normally. Then the mean value ($\bar{x}$) and standard deviation (sd) was determined for toluene concentration, eicosane concentration, and the total peak area.

Warning limits at $\bar{x}$ plus and minus 2 sd were established, and dashed lines drawn for the upper and lower warning limits (UWL and LWL). The control limits were set at $\bar{x}$ plus and minus 3 sd, and solid lines drawn for the upper and lower control limits (UCL and LCL). An example of a QC chart for toluene by manual sample injection is provided in Figure 11.

Two standard deviations from the mean for a normal distribution includes 95% of the data. Five percent of the data is expected to fall outside these limits and should not be cause for undue concern, but may be an indication that closer inspection of instrument performance is appropriate. Three standard deviations include 99.7% of the data. Any data outside the control limits of three standard deviations warrants serious attention and corrective action. Also, when two out of three control samples fall outside the warning limits, corrective action should be taken.

Kubic and Buscaglia (1991) recommend setting the warning limits at 1.5 sd from the mean and control limits at 2 sd. In our opinion, that criterion is too restrictive. By mandating corrective action for results at 2 sd from the mean, instruments that are performing in a normal manner would have to be placed out of service while an "out of control" situation is investigated. Statistically this could occur on a regular basis (approximately 5% of the time) and lead examiners to either perform unnecessary repairs and maintenance or develop a mistrust for the control charts. By establishing the control limits at a level where malfunctions are clearly identified, the charts become meaningful to the examiner and are used to improve instrument performance.

There is value in plotting the control sample and monitoring trends as they occur. An experienced examiner will learn to use control data as early warnings of potential malfunctions. Trends in data should be observed and correlated to routine maintenance requirements. When out-of-control conditions are indicated, the analyst uses skill and experience to determine what caused the change in instrument performance and performs corrective action. Additional information on preparing and using QC charts can be found in ASTM E882-87 (Reapproved 1992) - *Standard Guide for Accountability and Quality Control in the Chemical Analysis Laboratory*.

During periods of erratic QC chart (and possibly instrument) performance, analyzing additional known samples will demonstrate the quality of the data produced. Changes in the test mixture can be a source of change in the QC chart. To minimize evaporation of volatiles, several drops of water should be added to the solution. For long-term storage, aliquots of the test mixture should be placed in a freezer. Other than maintenance problems, a parameter we have observed to affect QC charts (and instrument performance) is the number of times an autoinjection needle is rinsed.

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Engineering Examinations in Arson Investigation

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Engineers are scientists with specialized training in specific fields, many of which are application oriented. Many engineers have an educational foundation of chemistry, physics, and math. On this foundation, the engineer may have specialized training in heat transfer, fluid dynamics, electrical theory, thermodynamics, and other areas. This training and education may give the engineer the capability to study fire. A special field of engineering—fire protection engineering—specifically deals with fire, its cause, prevention, and suppression. Many fire protection engineers have been called in after fires to help with an investigation and to learn what could have been done to prevent the fire or to put it out sooner.

OBJECTIVES

The most common concerns/objectives of a fire (arson) investigation are the determination of origin and cause. However, there are other issues which may also be of an equal or greater concern. These include fire development and spread from the point of origin, the rate of fire spread, smoke development and spread, and the egress of occupants (NFPA 1995). It is now possible to quantify or estimate these and to incorporate them in an overall fire analysis. An engineer who has had specific training and experience in these areas can be called in to a fire scene to collect the data necessary to make these estimates.

ORIGIN DETERMINATION

Fire scene examination includes observation of the patterns produced by the heat, flame, and smoke of the fire. These patterns may be useful in indicating where the fire originated. The shape, size, and intensity of a pattern may be useful in indicating the direction of fire spread and, by incorporating more than one pattern, the location of the source of the energy which produced the pattern may be determined. Further investigation may or may not indicate that the source of the energy was at the point of origin of the fire.

Pattern formation on the surfaces of a room and its contents is dependent on many environmental factors. These factors must be considered when observing and interpreting patterns. One factor which may be very important to pattern formation is ventilation. Ventilation of a compartment in which there is a fire will determine or influence the heat release rate, smoke production, temperature, flame size, and plume impingement points. Ventilation occurs through the openings present in the compartment when the fire starts and through any openings made by the fire as it grows. Windows are typically broken at some point during the fire and when they open, this may dramatically change the fire dynamics in the compartment. An analysis of the ventilation and its effect on the fire should be made and considered with the pattern analysis. A computer fire model may be helpful in evaluating the change in conditions as a result of different ventilation conditions. Fire protection engineers use computer fire models to evaluate fire growth and spread within buildings and these same models may be applied to fire investigation.

Another factor which may influence pattern formation and origin determination is the fuel load available in the room of origin. The fuel load and type of fuel will dictate how big a fire will get and the energy available from it. Fuel load evaluation is a common element of fire hazard and risk assessment done by fire protection engineers. Fuel load evaluation involves the inventorying of all combustible material in the rooms of interest and recording their approximate weight, composition, geometry, and placement within the room. After a

fire has occurred, this can be done from the remains of the fuel items, interviews with people familiar with the building, records, and other methods. Some amount of reconstruction may be necessary with the fire debris to establish where particular items were located. A large concentration of fuel in a particular area may influence fire pattern development, causing it to be more severe than expected or indicating a fire of longer duration. Knowledge of the fuel which produced the pattern will help in the analysis and understanding of the pattern.

The materials and methods used to construct the building where the fire occurred may also need to be considered when doing an origin analysis. An engineer familiar with the building construction and how fire behaves in this construction, would be helpful to an origin analysis. Certain construction features such as void spaces, insulation, wood joists, or insulating windows will influence fire spread.

CAUSE/IGNITION FACTOR DETERMINATION

Only after the origin of a fire has been located can the cause determination be started. The cause of a fire is the source and reason for the ignition energy. The ignition factor is the sequence of events which bring together all the elements necessary for ignition. It considers the fuel, its state, configuration, composition, and location relative to the source of ignition energy. Ignition factor also considers the ignition energy source including its temperature, energy content, and competency as an ignition source for the fuels being considered.

An important item in this analysis is the identification of the first material ignited. This is an engineering evaluation. It requires a study of the first material ignited including its ignition propensity, ignition temperature, and condition at the time of ignition. Standard test methods for determining ignition temperature may not be suitable or appropriate for evaluating a particular fuel under actual conditions. For this reason, ad hoc ignition tests may have to be devised to evaluate the ignition properties of a particular fuel under the conditions expected at the time the fire started. Such tests must be carefully designed to produce accurate and dependable results. Testing may be done in a laboratory or in the field. Field tests may be dictated by the particulars of the fire and allow for some demonstration of the fire events or conditions.

Engineers are often called in to evaluate materials and products. Evaluation may be to demonstrate that a particular item may or may not ignite under the specific circumstances of the fire being considered. These demonstrations can help to rule out different ignition sources and help the investigator to make a final cause determination. It is often necessary to create or simulate the conditions present when the fire occurred to get an accurate evaluation of the ignition scenario. Data gathered during these tests are generally both quantitative and qualitative in nature.

Quantitative data may include temperatures, mass, species concentration, radiant flux, and air velocities. This data collection requires specialized instrumentation, much of which is used by engineers in other areas. Typically a data collection system is also utilized to gather, store, and manipulate the data for presentation. Techniques and procedures from standard tests such as the American Society for Testing and Materials (ASTM) and the National Fire Protection Association (NFPA), may be adopted or modified for use.

Qualitative data is often collected from a fire test and may be just as important as the quantitative data. Qualitative data includes observation of fire behavior, fire growth, upper-layer development, smoke production, and other items which may be important to the particular fire being investigated. Engineers experienced in conducting fire tests and in observing fire behavior will be valuable in designing tests, setting up instrumentation, running the test, and interpreting the results. Fire tests of any size are expensive and for this reason repeat tests are not always possible and must be done correctly the first time.

Small scale laboratory tests may be useful to evaluate fuels or ignition sources. These include standard tests such as ASTM E-136 (ASTM 1982a) and UL 94 (UL 1990). These laboratory tests have been developed to evaluate a particular fire property of a material. With laboratory testing repeat tests are usually possible and should be done to ensure adequate data is collected. A material being tested should be as similar in composition, form, orientation, and size as the incident.

Evaluating ignition sources in the laboratory is often done, particularly to determine maximum temperatures and energy content. An ignition source may have a temperature which exceeds the ignition temperature of a material, but if it has insufficient energy or cannot transfer that energy, then it is not a competent ignition source. A good example of this is the spark produced by the arcing of a copper wire. The spark while still glowing has a temperature of

over 1500°F, which is greater than the ignition temperature of paper (NFPA 1995). But if the spark lands on a piece of paper after being ejected by the arc, it probably will not ignite the paper. This is because of the small size of the spark (mass), the loss of energy while the spark travels to the paper, and the fact that after the spark lands on the paper, not all of the energy gets transferred to the paper. This can easily be demonstrated in the laboratory.

Testing and demonstrations are also useful for presentation in court. Actually seeing the ignition process or developing fire can often help a jury and judge to better understand the work and testimony of an investigator. It should be expected that any tests or demonstrations done during the investigation may end up in court as part of criminal or civil proceedings. For this reason, care should be taken in the preparation of video tapes, photographs, and other documentation.

FIRE DETECTION SYSTEMS

After a fire starts, it gives off heat, light, and smoke. It is these products of combustion which may be detected by a fire detection system. Once a detection system has activated, an alarm should be generated and transmitted by the fire alarm system. In a fire investigation, the timing of events before and after the start of the fire is often an important element in understanding the fire. Expertise and experience with fire detection and alarm systems and their performance during a fire can be very helpful to an investigation. In this area, engineers and technicians who design and work with these systems are an important resource. They may use computer models which are available for predicting the response time of different detectors under specified fire conditions. These models may also be used to predict when a detector would have activated, had it been present. These computer models were developed by engineers to assist in the design and installation of these systems, and are readily adopted for use after a fire has occurred. They may also be applied to the activation of automatic sprinklers which are a type of heat detector. The engineer can gather sufficient data from the fire scene or from the investigation of others to run these computer models.

Control panels or alarm systems and monitoring services may have data on when various alarms were received and their status during the fire. There are many different manufacturers of fire detection and alarm equipment and each type of system will be different. Expertise directly from the manufacturer may be necessary to fully exploit these systems of the data they contain.

FIRE SUPPRESSION SYSTEMS

A building may also have a fire suppression system(s). These systems may or may not have activated during the fire. In either event, they will have to be examined and analyzed. The water-based automatic sprinkler system is the most common of these systems. They utilize a heat sensitive element which opens a sprinkler once an activation temperature has been exceeded, permitting water to flow. The water discharge is a cone-shaped pattern designed to disperse the water as droplets. This is usually an efficient and successful method of controlling the fire. The sprinklers open individually and the water will continue to flow until turned off at the source.

A sprinkler system failing to control a fire is considered an unusual event and should be investigated further. An engineer familiar with the design and operation of these systems should be utilized to analyze the performance of the system during the fire. The engineer can evaluate the system and the fuel load for which it was designed. The water supply to the system should also be examined. A sprinkler system may fail to control a fire because the fire hazard changed since the system was installed, the water supply was inadequate, the sprinklers were blocked by storage or construction, the system may have been deliberately impaired, or other reasons.

Fire suppression systems which are not water-based are less common and are usually installed to protect a special hazard. The performance of these systems should be evaluated in a similar way.

FIRE DEPARTMENT ACTIVITIES

The actions of a fire department in extinguishing a fire should also be considered in any fire investigation. From the moment the fire department arrives, they begin to change the fire scene. Expertise and experience in these activities are needed to understand their effect on the fire and how it may change the fire patterns.

Fire department personnel should be interviewed to determine the conditions on their arrival, what actions they took, and how the fire responded. Knowledge of how a fire department operates will help in these interviews.

FIRE GROWTH ANALYSIS

Once a fire is established, it will continue to grow under specific conditions. Some fires grow rapidly while others may self-extinguish. It is usually important to the investigation to know how the fire grew. It may indicate unusual or unexpected fuels which could indicate and prove an incendiary fire. This analysis requires an understanding of the fuel that was expected to be at the areas of origin and how it is expected to burn. Other factors besides just the fuel are important also, especially ventilation. An engineer analysis of the fuel and the conditions under which it burned may be necessary to completely explain what was observed about the fire. Outward appearances and quick conclusions about the fire cause and effect may be detrimental to the investigation. Computer fire models may help in this analysis as they allow the user to specify different fuels and to predict the effect these fuels have on the fire. The fire models may also be useful in predicting the effect of ventilation and other variables on the fire. Ultimately this analysis should be able to tell the investigator whether the rate at which the fire grew is possible without an outside influence like an accelerant. An important event in the growth of a fire and a component is flashover. Flashover is the nearly instantaneous ignition of all combustible fuel located in the room of origin. Flashover (and its indicators) is often reported by witnesses. Establishing the time at which flashover occurred, relative to other events, can often yield valuable information about the fire and the fuels present. Knowing what to ask witnesses about flashover and its manifestation is important in gathering accurate and useful information. For example, most people inexperienced with fire will describe flashover as an explosion. Flashover is not an explosion and should not be confused as such. Additional detailed questions about what was seen rather than a witness's interpretation of an event will be more helpful. Engineers and others who are experienced in these areas may participate in witness interviews by being present or by preparing questions for the interviewer. Either way, knowing what to ask and getting specific details often is very valuable to those who understand the dynamics of the fire.

SMOKE DEVELOPMENT

As smoke is typically the fatal element in a fire, its production and spread may need to be studied. The production of smoke is a function of the chemistry of fuel and its combustion. Different fuels produce different quantities of smoke and more with different characteristics like color and density. Observations about the smoke may help in the identification of the fuels involved and the combustion efficiency. Ventilation will have an important role in smoke production.

Smoke movement will depend on the size of the fire and the openings to the room of fire origin. Evaluation of smoke movement may yield information as to the status of these openings while the fire was burning. This opening status should be checked against what is normal or expected. There are computer fire models which deal with the production and movement of smoke and these can be utilized to test different possibilities and theories.

INCENDIARY FIRE CAUSE DETERMINATION

When an investigation has shown that the ignition factor may include a deliberate act, then the investigation will change. The actions of all people involved in the fire will be scrutinized under a different light. Likewise, the fire itself should be re-evaluated. The suspicion of an incendiary fire and the proof of that suspicion should not be without physical evidence. The proving of the crime of arson based on motive and opportunity alone is very difficult, and usually unnecessary.

If a fire was deliberately set, there will be physical indicators and evidence of that act. The investigation of the scene must continue until evidence is found or the cause should be listed as undetermined. Physical indicators of arson may be present away from the area of origin as well, and these areas should be searched more than once. The condition of all fire protection and life safety systems needs to be determined and documented. This is where the expertise and knowledge of a fire protection engineer would contribute to an arson investigation. Subtle and difficult-to-detect changes to these systems can compromise their effectiveness. If the person setting the fire knows that these systems may prevent him from accomplishing the goal of the fire, then he will have to do something to prevent or limit their expected operation. It may be that the operation of a fire suppression system is the desired goal for the purpose of causing property damage. With these systems, it is not as simple as closing a water supply valve or turning off the power. There are codes which govern the design and installation of these systems and they usually require that monitoring be provided of any component which is essential to the operation of the system. Valves would have a tamper alarm and an alarm system would have power monitoring and battery backup.

Not only deliberate sabatoge to a protection system can compromise their effectiveness; these systems require regular maintenance and testing. A building owner who deliberately fails to keep these systems in good working order will be violating one or more building or fire codes. The building owner may also be preparing for a fire. Knowledge of the maintenance and testing requirements will assist the investigation by identifying what should have been done and what is the effect of this omission. Evidence of a lack of the required maintenance and testing to these systems should be as carefully examined as insurance records.

After a fire has occurred, it may be necessary to test a fire protection system to determine why it functioned the way it did. It may also be necessary to inspect components of these systems by disassembly. This disassembly may or may not be destructive. Any type of testing or disassembly requires the appropriate cautions, notifications, and procedures as outlined in ASTM E-860 (ASTM 1982b). In this process, an engineer familiar with these systems would be valuable and should be utilized.

CONCLUSION

Fire investigation, like other forensic investigations, is becoming increasingly complex. The fire science and fire protection engineering fields have greatly expanded in their knowledge and understanding of how fire behaves. This knowledge has been slow to transfer into the fire investigation field. Many of the tools of the engineer can significantly contribute to a fire investigation. The complexity of modern fire protection systems practically requires that an engineer be utilized. A good investigation is one which leaves no stone unturned and which has utilized all available resources.

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The Legal Aspects of Arson Investigation - The *Tyler/ Clifford* Legacy

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The United States Supreme Court has decided only two cases directly relating to the Fourth Amendment implications of warrantless, nonconsensual origin and cause investigations.[1] In each of the cases, the Court reversed the defendant's conviction after conducting a sweeping analysis of the constitutionality of governmental intrusions into private buildings for purposes other than in search of the fruits and instrumentalities of crime. The court found that "[t]he decisions of this Court firmly establish that the Fourth Amendment extends beyond the paradigmatic entry into a private dwelling by a law enforcement officer in search of the fruits and instrumentalities of crime."[2] The court further held that while the purpose of a governmental intrusion might simply be to locate and abate public nuisances, to perform routine periodic inspections, or to conduct an origin and cause investigation, such an intrusion nevertheless invaded the privacy of the occupants and are, therefore, within the protection of the Fourth Amendment.[3]

The Court in both *Tyler* and *Clifford* made it abundantly clear that there is no diminution in a person's reasonable expectation of privacy, nor in the protection of the Fourth Amendment, simply because the official conducting the search wears the uniform of a firefighter rather than a policeman.[4] In addition, the Court was also clear that the fact that an entry is merely for the purpose of ascertaining the cause of a fire, rather than to look for evidence of a crime, or because the fire might have been started deliberately, does not result in any diminution in the occupant's Fourth Amendment protections.[5] Therefore, an arson investigator's entry into a structure to conduct an origin and cause investigation must comply with the warrant procedures of the Fourth Amendment.[6]

While the Court held in both cases that the nonconsensual entry and search of property is governed by the warrant requirement of the Fourth and Fourteenth Amendments,[7] the Court also recognized that a warrantless entry by criminal law enforcement officials may be legal when there is compelling need for official action and no time to secure a warrant.[8] The Court determined that "[a] burning building presents an exigency of sufficient proportions to render a warrantless entry 'reasonable'."[9] In fact, the Court felt that it would be illogical and defy reason to require a firefighter to obtain a warrant or consent before entering a burning building to put out a fire.[10] The Court also determined that any evidence of arson found by the firefighters during suppression activities would be admissible pursuant to the plain view doctrine.[11] Finally, the Court held that the firefighters may remain in the location for a reasonable time after the suppression activities are completed to conduct an investigation into the cause of the blaze.[12]

At first look it would appear that *Tyler* and *Clifford* have provided a clear standard for determining when a search warrant is required for an origin and cause investigation at a fire scene. A closer look at these cases, and the subsequent appellate decisions surrounding the issue of fire cause investigations, establishes that these two cases have created a great deal of confusion as to the Fourth Amendment parameters of an origin and cause examination. As Chief Justice Rehnquist noted in his dissent in *Clifford*, "... today's opinion, far from clarifying the doubtful aspects of *Tyler*, sows confusion broadside."[13] This article will examine the Court's pronouncements in *Michigan* v. *Tyler*, *Michigan* v. *Clifford*, and how these conflicting opinions have been

applied by the state and lower federal courts. It is hoped that, through such a careful analysis of the cases, the suppression of significant evidence found during origin and cause investigations can be avoided.

MICHIGAN v. *TYLER*[14]

The Facts

Shortly before midnight on January 21, 1970, a fire occurred in a furniture store owned by Loren Tyler and Robert Tompkins. The fire department responded to the fire and had completed the suppression of the fire when Fire Chief See (who was responsible for determining the cause and making reports) arrived on scene at approximately 2:00 a.m. Upon his arrival, Chief See was informed by Lieutenant Lawson that two plastic containers of flammable liquid had been found in the building. Using portable lights, Chief See and Lieutenant Lawson entered the location to examine the containers.

After determining that the fire could possibly be arson, Chief See contacted Police Detective Webb who arrived at about 3:30 a.m. Detective Webb took several pictures of the containers and the interior of the location, but ceased further investigation because of smoke and steam. By 4:00 a.m. the fire was extinguished and the firefighters departed. Detective Webb and the fire chief removed the containers and left the location.

At approximately 8:00 a.m., Chief See and Assistant Chief Somerville (whose job was to determine the origin of all fires that occurred) returned to the location. After a cursory examination, they both left the location. About 1 hour later, Assistant Chief Somerville and Detective Webb returned to the location and discovered suspicious burn marks and other evidence that they were unable to see earlier that morning. After digging through the rubble to locate other signs or evidence that showed how the fire started, they removed pieces of carpet and a section of the stairs that were suggestive of a fuse trail.

Finally on February 16, 1970, a member of the state police arson section made an inspection of the location and took photographs. The state police officer made several other subsequent visits to the location, at which time additional evidence and information was obtained. Over the course of several visits, the state police officer secured physical evidence and formed opinions that were introduced in evidence against Loren Tyler and Robert Tompkins.

The Court's Opinion

In examining the constitutionality of the numerous entries, the Court first noted that "[a] burning building clearly presents an exigency of sufficient proportions to render a warrantless entry 'reasonable'."[15] The Court held that the original entry by the firefighters to extinguish the fire at Tyler's Auction House did not violate the Fourth and Fourteenth Amendments, nor did Chief See's removal of the two plastic containers of flammable liquid found on the floor of one of the showrooms.[16]

The Court then turned to the question of when the exigency justifying the initial entry by the firefighters ends. In concluding that fire investigators may remain in a building to investigate the cause of a fire after suppression activities have been completed, the Court noted that "[f]ire officials are charged not only with extinguishing fire, but with finding their causes."[17] The Court went on to find that a "prompt determination of a fire's origin may be necessary to prevent its recurrence, as through the detection of continuing dangers such as faulty wiring or a defective furnace; immediate investigation may also be necessary to preserve evidence from intentional or accidental destruction; and, of course, the sooner the officials complete their duties, the less will be their subsequent interference with the privacy and the recovery efforts of the victims."[18] The Court then held that the warrantless seizure of evidence while inspecting the premises for the purpose of determining the cause of the fire was constitutional.[19] Finally, the Court noted that once an investigator finds probable cause to believe that arson has occurred and requires further access to gather evidence for a possible prosecution, the access must be pursuant to a warrant issued upon the traditional showing of probable cause applicable to searches for evidence of a crime.[20]

While the holdings in *Tyler* appear clear, an examination of how the subsequent federal and state appellate decisions apply the *Tyler* holdings reveals the difficulties that courts have had in applying the *Tyler* standards. As Circuit Judge Nathaniel R. Jones noted in his dissenting opinion in *United States* v. *Urban*,[21] "[w]hile the general principles of *Michigan* v. *Tyler* appear clear, the difficulty in determining the reach of its precise holding is apparent not only from this panel's inability to agree on its application to the present facts, but from the district court's obvious need to wrestle with the issue and from the Supreme Court's recent grant of certiorari in a Michigan state court case dealing with this precise question."[22] Thus, the questions of when an entry by an arson

investigator is permissible due to exigent circumstances and when the "further access" provisions of *Tyler* are applicable at a fire scene has engendered confusion among the federal appellate courts and state courts from *Tyler's* inception. Therefore, the Supreme Court apparently chose to attempt to clarify the *Tyler* issues by granting certiorari in *Michigan* v. *Clifford*.[23]

Michigan v. *Clifford*[24]

The Facts

In the early morning hours of October 18, 1980, a fire erupted in the home of Raymond and Emma Jean Clifford. The fire was reported to the Detroit Fire Department and the fire units arrived on the scene at approximately 5:40 a.m. The fire was extinguished and all fire personnel had left the scene by 7:04 a.m.

At approximately 8:00 a.m., Lieutenant Beyer (a fire investigator with the arson section of the Detroit Fire Department) received instructions to investigate the fire. Lieutenant Beyer was also advised that the fire department suspected that the fire was arson. Lieutenant Beyer and his partner arrived at the fire scene at approximately 1:00 p.m.

Upon his arrival at the scene, Lieutenant Beyer found a work crew boarding up the house and pumping some six inches of water out of the basement. A neighbor informed the Lieutenant that the Cliffords were out of town and did not plan to return that day, but that they had requested the neighbor to instruct their insurance agent to secure the premises. While the investigators waited for the water to be pumped out of the basement, they found a Coleman fuel can in the driveway that was seized and marked as evidence.

At about 1:30 p.m., the water had been pumped out of the basement and the Lieutenant and his partner entered the residence and began their investigation into the cause of the fire. Their search began in the basement and they quickly confirmed that the fire had originated beneath the basement stairway. They detected a strong odor of fuel throughout the basement and found two more Coleman fuel cans beneath the stairway. As they dug through the debris, the investigators found a crock pot with attached wires leading to an electrical timer that was plugged into an outlet a few feet away. The timer was set to turn on at approximately 3:45 a.m. and to turn back off at approximately 9:00 a.m.; the timer had stopped somewhere between 4:00 a.m. and 4:30 a.m. All of this evidence was seized and marked.

After determining that the fire had originated in the basement, Lieutenant Beyer and his partner searched the remainder of the house. The investigators called in a photographer to take pictures throughout the house. They searched through drawers and closets and found them full of old clothes. They inspected the rooms and noted that there were nails on the walls, but no pictures hanging from the nails.

The Court's Opinions

Because the Court in *Michigan* v. *Clifford* was deeply divided, no majority of Judges joined any one opinion written in the case. The Court's ruling was based on a plurality opinion.[25] This plurality resulted in four Judges writing an opinion of the Court, one Judge joining in the conclusion of the Court's opinion, and four Judges dissenting from the Court's opinion. The failure of any one faction to obtain the support of five Judges in *Clifford* has served to greatly increase the uncertainty and confusion concerning the constitutionality of warrantless, nonconsensual searches to determine the origin and cause of a fire.

The Plurality Opinion

In reversing the conviction of the Cliffords, the plurality reaffirmed that "[e]xcept in certain carefully defined classes of cases,[26] the nonconsensual entry and search of property are governed by the warrant requirement of the Fourth and Fourteenth Amendments."[27] Yet, the Court also noted that a nonconsensual, warrantless entry may still be constitutional depending on whether the owner has a reasonable expectation of privacy in the fire-damaged property, whether the existing exigent circumstances justify the intrusion irrespective of the expectation of privacy, and whether the object of the search is to determine the cause of the fire or to gather evidence of criminal activity.[28]

In turning to the specific facts of the search in *Clifford*, the plurality found that the search by Lieutenant Beyer was not a continuation of an earlier search.[29] In reaching this conclusion, the plurality noted that at the time the arson investigators arrived, the firefighters had extinguished the blaze and left the scene. In addition, the Court noted that the Cliffords had taken steps to secure the privacy interests that remained in their residence by beginning to board up the structure.[30] These efforts by the owner to secure the premises separated the entry made to extinguish the blaze from that made later by different officers to investigate its origin.[31] Therefore, the plurality held that, "[a]t least where the homeowner

has made a reasonable effort to secure his fire-damaged home after the blaze has been extinguished and the fire and police units have left the scene, ... a subsequent post-fire search must be conducted pursuant to a warrant, consent, or the identification of some new exigency."[32]

The plurality's opinion did recognize that "some fires may be so devastating that no reasonable privacy interests remain in the ash and ruins, regardless of the owner's subjective expectations."[33] The plurality's opinion would require that the fire investigator make a determination as to whether a reasonable privacy interest remains in the fire-damaged property.[34] "Where, ... reasonable expectations of privacy remain in the fire-damaged property, additional investigations begun after the fire has been extinguished and fire and police officials have left the scene, generally must be made pursuant to a warrant or the identification of some new exigency."[35]

A practical examination of the factors relevant to the plurality's opinion in *Clifford* makes it evident that the opinion has placed fire investigators in a difficult position at every fire scene. In the absence of a warrant, the investigator has to determine whether the type of property, the amount of fire damage, the prior and continued use of the premises, and the owner's efforts to secure it against intruders create an objectively reasonable expectation of privacy in the premises.[36] If the investigator believes the court is likely to find a reasonable expectation of privacy, then a warrant may be needed for the cause and origin investigation.[37]

Once the investigator has evaluated the expectation of privacy factors, he or she would also need to determine whether there was any evidence indicating that a criminal act caused the fire. Since the Court felt that the object of the search was important even if exigent circumstances exist, if the fire is potentially an arson then a criminal warrant is necessary.[38] If the cause of the fire is unknown, the investigator will be able to search without a warrant if there is no expectation of privacy[39] or with an administrative warrant if there is an expectation of privacy.[40]

The Concurring Opinion

In concurring in the judgment announced in the plurality opinion, Justice Stevens noted that because he continued "to hold the views expressed in my separate opinions in *Michigan* v. *Tyler* ...," he was unable to join in the plurality opinion.[41] However, Justice Stevens did feel that the Court was unanimous on three general propositions regarding the Fourth Amendment protection afforded to the owner of fire-damaged property.[42] "No one questions the right of firefighters to make a forceful, unannounced, nonconsensual, warrantless entry into a burning building ... Nor is there any disagreement concerning the firemen's right to remain on the premises, not only until the fire has been extinguished and they are satisfied that there is no danger of rekindling, but also while they continue to investigate the cause of the fire. We are also unanimous in our opinion that after investigators have determined the cause of the fire and located the place it originated, a search of other portions of the premises may be conducted only pursuant to a warrant issued upon probable cause that a crime has been committed and specifically describing the places to be searched and the items to be seized."[43]

In agreeing with the plurality's conclusion that the 1:30 p.m. search by Lieutenant Beyer was violative of the Fourth Amendment, Justice Stevens noted that the investigators (who arrived after the firefighters had left) were not on the scene prior to the completion of the suppression activities, and that an earlier investigation was not suspended due to conditions at the scene.[44] Justice Stevens concluded that "[i]n general, unless at least some of the same personnel are involved in a return to the premises and the temporary departure was justifiably and actually occasioned by the conditions at the premises, I would apply the test expressed by Justice White for measuring the scope of the emergency that justified the initial entry and search: 'Once the fire has been extinguished and the firemen have left the premises, the emergency is over'."[45]

While Justice Stevens believed that the Fourth Amendment would require a fire investigator to obtain a traditional criminal search warrant to make an unannounced entry, he "would characterize a warrantless entry as reasonable whenever the inspector either had given the owner sufficient advance notice to enable him or an agent to be present or had made a reasonable effort to do so."[46] Thus, under Justice Stevens' approach, in the absence of probable cause to believe the fire was an arson, a fire investigator would only need to make reasonable efforts to provide the owner of the premises with notice of his intent to examine a premises for the purpose of ascertaining the cause of a fire.[47] Under this approach, as long as notice is given to the owner of a premises, a warrantless, nonconsensual search of a fire-damaged premises will be constitutional.[48] Justice Stevens " ... therefore concluded that the search in this case (*Clifford*) was unreasonable in

contravention of the Fourth Amendment because the investigators made no effort to provide fair notice of the inspection to the owners of the premises."[49]

It is apparent that Justice Stevens' approach to a fire origin and cause investigation would provide a great deal of latitude to the fire investigator. Regardless of the owner's expectation of privacy, the investigator could enter and conduct an investigation as long as reasonable efforts had been made to provide notice to the owner of the premises. Thus, Justice Stevens' approach appears to strike a balance between the stringent requirements of the plurality and the completely warrantless approach of the dissent.[50]

The Dissent

After noting that the plurality opinion in *Clifford* sowed confusion surrounding the Fourth Amendment issues relating to fire cause investigations, the dissent concluded "that the exigent circumstances doctrine enunciated in *Tyler* authorized the search of the basement of the Clifford home."[51] However, the dissent did find that the search of the remaining parts of the house could not have been searched without the issuance of a warrant issued upon probable cause.[52] The dissent based their determination on the belief that a fire investigator's entry onto a premises is not authorized until the occurrence of a fortuitous or exigent event over which the firefighters have no control.[53] "Thus, if the warrant requirement exists to prevent individuals from being subjected to an unfettered power of government officials to initiate a search, a warrant is simply not required in these circumstances to limit the authority of a fire investigator, so long as his authority to inspect is contingent upon the happening of an event over which he has no control."[54]

Since the concerns regarding administrative searches are not present in a fire investigation conducted within a reasonable time of the fire,[55] the need for a magisterial evaluation of the grounds for a search, following a fire, " ... is so limited that the incidental protection of an individual's privacy interests simply does not justify imposing a warrant requirement."[56] "In the aftermath of a fire, an individual is unlikely to have much concern over the limited intrusion of a fire inspector coming into the premises to learn why there had been a fire. Fire victims, unlike occupants at ordinary times, generally expect and welcome the intrusions of fire, police, and medical officials in the period following a fire."[57] The dissenting Justice thus reached the conclusion that the intrusion of the fire inspector is not substantially different from the initial entry made by the firefighters.[58]

Therefore, the key determination of the dissenting opinion is whether a reasonable search was conducted in a reasonably timely manner. It is apparent that under such a standard, reasonable time and scope restrictions can be established without continuously conducted case-by-case analysis. The courts can then easily apply the standards to the individual facts of each case and reach a relatively consistent conclusion.

ADMINISTRATIVE AND CRIMINAL SEARCH WARRANTS[59]

In both *Tyler* and *Clifford* the United States Supreme Court undertook an analysis of when a warrant is required for an origin and cause investigation. In examining the question, the Court stated that the major function of the warrant is to provide the property owner with sufficient information to reassure him of the entry's legality.[60] While the Court's opinions were less than clear on the parameters of when a warrant is necessary, there were some clear pronouncements concerning the use of warrants to conduct origin and cause investigations.

If the primary object of the search is to determine the cause and origin of an undetermined recent fire, an administrative warrant will suffice.[61] To obtain an administrative warrant, the fire investigator will need to show that a fire of undetermined origin occurred on the premises, that the scope of the proposed search is reasonable and will not intrude unnecessarily on the fire victim's privacy, and that the search will be executed at a reasonable and convenient time.[62] Since this type of administrative warrant (a nonprogramatic warrant)[63] is not based on any standardized criteria, the number of prior entries, the scope of the search, the time of day when it is proposed to be made, the lapse of time since the fire, the continued use of the building, or the owner's efforts to secure it against intruders, these might all be relevant factors that a magistrate should consider in evaluating the request.[64] Under these circumstances, the magistrate's duty is to assure that the requested intrusion is reasonable and will not unduly disrupt the occupant.[65] Yet, if evidence of criminal activity is discovered during the course of a valid administrative search warrant, it may be seized under the plain view doctrine.[66] However, the evidence of criminal activity seized cannot be used to expand the scope of the administrative warrant without the investigator first making a showing of probable cause to a neutral magistrate.[67]

If the primary object of the search is to gather evidence of criminal activity, a criminal search warrant may be obtained only on a showing of probable cause to believe that a crime has occurred.[68] In addition, the investigator will need to establish that relevant evidence will be found in the place to be searched.[69] Assuming that the investigator can establish the necessary probable cause for the issuance of the warrant and the necessary particularity as to the items to be seized, the warrant would be served in the same manner as any other warrant based on probable cause without regard to prior entries and inconvenience to the owner.

WARRANTLESS/NONCONSENSUAL ENTRY

In *Welsh* v. *Wisconsin*[70] the Supreme Court held that absent probable cause and exigent circumstances, searches and seizures inside a home without a warrant are unreasonable.[71] It is upon this foundation that the Supreme Court based its opinions in *Tyler* and *Clifford*. While in each of the opinions the Court discussed the warrant requirements, the Court also determined that the aftermath of a fire often will not tolerate the delay necessary to obtain a warrant or to secure the owner's consent to inspect fire-damaged premises.[72] The Court, therefore held, that because determining the origin and cause of a fire serves a compelling public interest, the warrant requirement would not apply in such circumstances.[73]

However, since every fire will occur under different circumstances, it is evident that the question of whether a particular warrantless, nonconsensual entry is constitutional will necessarily have to be left to a case-by-case analysis.[74] When this case-by-case analysis is combined with the confusion in the *Tyler* and *Clifford* decisions, it is apparent that the conclusions of the federal and state appellate courts would vary dramatically in similar circumstances. Therefore, it is imperative that the fire investigator be thoroughly familiar with the potential implications before making a warrantless, nonconsensual entry into a fire-damaged premises.

The initial determination hurdle to a warrantless, nonconsensual search is a finding that an exigency exists. Exigent circumstances are those circumstances that would lead a reasonable person to believe that entry was necessary to prevent physical harm to the investigator or other persons and to protect or preserve life, the destruction of relevant evidence, or other consequences frustrating legitimate law enforcement efforts.[75] As the Supreme Court noted in *Tyler* and *Clifford*, a fire creates an exigency of sufficient magnitude to allow the entry of firefighters to extinguish the fire and the entry of an arson investigator for a reasonable period of time after the blaze is extinguished to determine the origin and cause of the fire.[76] However, the courts have varied dramatically in their conclusions as to whether there was a sufficient exigency still present at the time of entry by the arson investigator.

In *United States* v. *Warner*[77] the Ninth Circuit of the Court of Appeals reviewed a search of the defendant's garage and the seizure of chemicals used in the manufacture of narcotics that was conducted pursuant to the landlord's request. In affirming the District Court's granting of a motion to suppress evidence, the court found that the existence of an exigency must be viewed from the totality of the evidence known to the officer at the time of the warrantless intrusion.[78] The court noted that the Fourth Amendment does not permit an officer to make a search and then seek its justification.[79] Therefore, the court held that at the time of the search, the officer was unaware that any illicit activity was taking place, and that the officer was unaware of the volatility of the chemicals and that there was any immediate emergency.[80]

In *Swan* v. *Superior Court*[81] the California Court of Appeal examined the constitutionality of a fire origin and cause investigation that occurred 10 days after the premises was destroyed by fire. In holding that the search was conducted in violation of the Fourth Amendment, the court noted that "[t]he entry was not made under emergency circumstances, but in furtherance of a routine police investigation 10 days after the alleged crime was committed."[82] The court held that when the investigators entered the location 10 days after the fire, they possessed probable cause to believe that the premises contained evidence which might assist in the prosecution of the defendant.[83] The court based this conclusion on the fact that one of the investigators had completed an origin and cause investigation on the date of the fire.[84] The court found that under such circumstances, the subsequent re-entry was to gather evidence for the criminal prosecution and not to determine the cause and origin of the fire.[85]

In *People* v. *Holloway*[86] the Illinois Supreme Court examined an origin and cause investigation that was begun 2-1/2 hours after the firefighters had suppressed the fire and left the location. In reversing the defendant's conviction, the court found that while the exigent circumstances created by a fire do not end with the dousing of the last flames, once the fire is out and the exigency has abated, a warrantless entry by fire officials will not be permitted.[87]

The court noted that fire officials will generally not violate the Fourth Amendment by conducting a prompt fire-scene investigation.[88] However, the court determined that "[t]he privilege of commencing an investigation and then leaving the scene and later returning without a warrant is not extended simply because of the fact that the structure has burned."[89] Therefore, the court held that the privilege to begin an investigation without a warrant may not survive a departure and return absent an emergency situation.[90] Since the firefighters had completed suppression activities and left the location, the court determined that the conclusion that no exigent circumstances existed was apparent and, therefore, the State's interest in prompt investigation must yield to the individual's reasonable expectation of privacy in the burned premises.[91]

The court distinguished the instant case from *People* v. *Calhoun*,[92] noting that unlike the investigator in *Calhoun*, this investigator was told of the suspicion of arson and failed to promptly respond, thus, conclusively establishing that the primary purpose for his investigation was to search for evidence of a crime.[93] The court, thus, held that the origin and cause investigation was detached from the initial emergency created by the fire and was made in violation of the defendant's Fourth Amendment rights.[94]

In *State* v. *Hansen*[95] the Iowa Supreme Court examined an investigation by a regional State Fire Marshal that did not begin until the day after the fire was suppressed. The court found that "[t]he inspection by the regional Deputy Fire Marshal ... constitutes an additional entry under the *Tyler* standard."[96] The court noted that there were no exigent circumstances which could have justified such a warrantless entry, especially in light of the fact that the fire was not of major proportions, the building was left unattended, and apparently re-ignition was not a major concern.[97]

In *Passerin* v. *State*[98] the Delaware Supreme Court examined the constitutionality of a re-entry 24 hours after an initial investigation, and the securing of the premises for multiple re-entries over a 5-day period. In suppressing the observations and conclusion which occurred after the initial investigation, the court noted "that the Deputy Fire Marshal's re-entry of the defendant's premises ... nearly 24 hours after the fire had been extinguished and some 21 hours after Kiley (the initial investigator) had voluntarily terminated his investigation, was 'clearly detached from the initial exigency and warrantless entry' made by Kiley on the day of the fire. Hence, it and all later re-entries cannot reasonably be said to have been 'no more than an actual continuation of the first entry'."[99]

After *Passerin* was remanded for further proceedings, the case again returned to the Delaware Supreme Court on appeal by the State. In *State* v. *Passerin*[100] (after noting that the State had presented no new evidence to the trial court) the court found that when the initial investigation was voluntarily terminated, the investigator had probable cause to suspect arson at the location.[101] In addition, the court noted and the State conceded that when the investigator left the location, the owner locked the exterior gate to the overall grounds. The court determined that the locking of the gate eliminated any danger that evidence would be lost or destroyed.[102] The court, therefore held, " ... that where no exigent circumstances exist, and in the face of probable cause that a crime has been committed, the law is peremptory in its requirement that persons responsible for investigating the cause of fire first obtain search warrants before entering another's premises without proper consent."[103]

In *United States* v. *Callabras*[104] the Second Circuit of the Court of Appeals examined the entry into a house by narcotics investigators after the initial fire investigation had revealed the existence of chemicals used to manufacture narcotics. In upholding the defendant's conviction, the court noted that regardless of what the investigator hoped to accomplish by seizing the items, prompt action to remove the dangerous chemicals was still required.[105] The court noted that the 3-hour delay between suppression and the arrival of the narcotics expert did not diminish the exigency since the Fourth Amendment would not require the disposal of the chemicals by the original investigators despite their lack of expertise.[106]

In *United States* v. *Moskow*[107] the Third Circuit of the Court of Appeals reviewed an entry into the defendant's vacant building after a neighbor had complained of hearing noises in the location. In upholding the entry the court noted that the police were responding to specific information of a surreptitious entry into a vacant building at a late hour of the night and detected a strong odor of gasoline coming from the building.[108] The court noted that the police could not realistically preclude the possibility of any reckless behavior on the part of the intruder who possessed the quantity of gasoline evident from the fumes.[109] The court therefore held that "[i]t would defy all reason for a fire marshal to secure a warrant before entering a structure to prevent a fire by ordering the building ventilated and by seizing three empty gasoline cans and a 'Bic' lighter."[110]

In *State* v. *Olsen*[111] the Minnesota Supreme Court examined the constitutionality of an investigation that was begun approximately 15 minutes after the

firefighters left the location. The court initially noted that in the instant case, unlike *Tyler*, the investigation was not initiated prior to the departure of the firefighters.[112] However, the court held that the subsequent warrantless entry was justified by the same exigencies that would have justified the firefighters remaining on the scene in the first instance.[113] The court found that prompt investigation is necessary to help prevent a recurrence of the fire, and, thus, serves to protect the public safety.[114] In addition, the court determined that a prompt investigation also serves to minimize the risk that evidence of the origin and cause will be destroyed by accidental or intentional actions.[115]

Finally, relying on the language of *Tyler*, the court noted that " ... a prompt investigation interferes the least 'with the privacy and the recovery efforts of the victims'."[116] The court felt that the delay in beginning the investigation did not in any way increase the threat of interference with the victim's privacy and was not of such a magnitude to diminish the necessity and validity of making a prompt investigation.[117] Therefore, the court held that, " ... little purpose would have been served by the firefighters having remained on the scene an extra 15 minutes until Palmquist (the first investigator) arrived to begin the fire investigation."[118]

In *Davis* v. *State*[119] the Court of Appeals of Texas examined the constitutionality of a fire investigation of a mobile home. In upholding the entry into the premises 1 day after the fire, the court noted that an examination of the photographs of the premises revealed that the location was so badly damaged that the possibility of anyone having a reasonable expectation of privacy in the location was precluded.[120] The court determined that as the United States Supreme Court recognized in *Clifford* "[s]ome fires may be so devastating that no reasonable privacy interests remain in the ash and ruins, regardless of the owner's subjective expectations."[121] In addition, the court noted that the defendant had taken no measures to secure the remains of the location from intrusion.[122]

In *State* v. *Langley*[123] the Court of Appeals of North Carolina examined an origin and cause investigation that began while suppression activities were ongoing. In upholding the investigation, the court found that " ... while firemen are present at a fire and engaged in any continuing activity to bring under control, extinguish a fire, or prevent re-ignition, a search for the possible presence of accelerants on the premises may reasonably be conducted without a search warrant and without regard to how or why any accelerants may have been placed or stored on the premises, and that the fruits of such a search are admissible in evidence against any person charged with an unlawful burning of or upon the premises."[124]

In *State* v. *Burge*[125] the Court of Appeals of Louisiana reviewed an origin and cause investigation that was suspended due to darkness and smoke at the time of suppression and re-entry made 15 hours after suppression activities had been concluded. The court noted that, as in *Tyler*, the investigation was discontinued because of darkness and smoke, and unlike in *Tyler*, the investigator notified the owner of the premises that he would return on the following day.[126] The court noted that while the investigation was not resumed until after the volunteer fire investigator completed his regular work day, "the lapse of several hours did nothing to change the character of the search as a mere continuation of that previously begun."[127] The court found that the continuous nature of the investigation was evident from the fact that the defendant was informed on the night of the fire that the investigation was not complete and would resume the following day.[128]

Therefore, the court found that while reasonable diligence in resuming the investigation should be required, a more important consideration is whether the subsequent search is conducted to complete a job which, due to unavoidable circumstances (*i.e.*, darkness and smoke), was necessarily postponed or whether the subsequent search is conducted to gather evidence for a criminal prosecution.[129] The court went on to hold that " ... to qualify as a continuation of an initial fire investigation postponed by darkness, a search need not be resumed at the break of day."[130]

The court also determined that a close examination of *Clifford* revealed that the significant factor in the Court's decision was the owner's efforts at securing the premises, and not the mere lapse of time between the departure of the firefighters and the arrival of the arson investigators.[131] Thus, the court found that the language of *Clifford* was consistent with the court's view that the lapse of time between the postponement of the initial investigation and the subsequent resumption is not the most important factor in determining whether the subsequent search may be considered a continuation of the initial investigation.[132] The court noted that the record in *Burge* failed to establish any efforts on the part of the defendant to secure the building from entry during the period between the initial investigation and the re-entry on the following day.[133] The court held that neither the heightened expectation of privacy in a residence or efforts to secure the premises, were present in this case.[134]

In *People* v. *Avalos*[135] the California Court of Appeal examined a warrantless entry into a premises conducted by a Deputy Sheriff after firefighters observed a drug laboratory during efforts to suppress a fire. In upholding the initial warrantless entry, the court noted that a burning building creates an exigency that justifies a warrantless entry by fire officials to fight the blaze,[136] and that such justification does not end immediately with the suppression of the fire.[137] In addition, the court noted that California courts have long recognized the potential exigencies, independent of those of a fire, created by an illegal methamphetamine laboratory.[138] Based on these factors, the court held that "[t]he firefighters' discovery of apparatus consistent with a methamphetamine laboratory, combined with the fact of the outbreak of fire, warranted re-entry to investigate the possibly volatile situation with the danger of future, if not immediate, fire hazard."[139] The court further noted that under Tyler, the lack of evidence of an emergency situation requiring immediate danger to life or damage to property did not preclude a warrantless re-entry.[140]

In *People* v. *Glance*[141] the California Court of Appeal reviewed an investigation that began as the fire was suppressed, but was conducted by an arson investigator who testified that his specific purpose in examining the location was to determine whether any evidence of arson existed in the location.[142] During the course of his investigation, the investigator discovered evidence of narcotics use and requested a narcotics expert for the location. In upholding the initial search and the subsequent search by the narcotics expert, the court stated "[w]e agree with the court in *United States* v. *Green*[143] which aptly explained: 'The purpose of a search warrant is to ensure judicial authorization in advance of intrusions into constitutionally protected privacy ... [However] [o]nce the privacy of a dwelling has been lawfully invaded to require a second officer from another law enforcement agency ... to secure a warrant before he enters the premises ... is just as senseless as requiring an officer to interrupt a lawful search to stop and procure a warrant for evidence he has already found and seized."[144] The court went on to note that both fire and police personnel are agents of the state, and both are subject to Fourth Amendment requirements.[145] Once a fireman has lawfully entered a burning building, "the invasion of privacy is not increased by an additional officer, albeit a [police] officer," entering the edifice to seek out the fire's genesis.[146]

From an examination of these cases, it is evident that a warrantless, nonconsensual search of a fire-damaged location is a perilous act. While the vast majority of fire victims will not object to such a search, the "victims" who will always object to the search will usually not do so until faced with criminal charges for their fire. Therefore, an arson investigator acts at the peril of a criminal conviction when he or she conducts an arson investigation without a warrant or consent.[147]

SUSPICION OF ARSON

In addition to the question of exigency, many of the courts have viewed the investigator's state of mind as relevant to the reasonableness of the entry. As previously discussed, the Court in *Clifford* felt that the investigator's state of mind, as to the existence of evidence of arson, was relevant to the question of exigency.[148] Therefore, the investigator must also consider the information he has about the origin and cause of the fire before making entry into the location.

In *State* v. *Buxton*[149] the Indiana Supreme Court, in a case preceding *Tyler* and *Clifford*, reviewed an investigation that began the day after a fire damaged the interior of the defendant's restaurant. While the court failed to discuss the issue of the constitutionality of the initial entry into the location, the court found that the search was violative of the Fourth Amendment.[150] The court noted that while a photographer was taking a picture of the area of origin, he located evidence indicative of an incendiary fire.[151] The court held that " ... [i]t cannot well be maintained that the search made was a mere civil inspection and, even if it began as such as the state contends it may have, no good reason is shown why a search warrant was not obtained at the point in time when evidence believed to be incriminating was discovered."[152] The court determined that from the point in time when the investigation was conducted for the purpose of obtaining incriminating evidence against the owner of the property, a search warrant was necessary.[153]

In *People* v. *Rammouni*[154] the Court of Appeals of Michigan reviewed an investigation that began while the firefighters were suppressing the fire,[155] continued during 2 hours of suppression activity, and was resumed approximately 5 hours later on the morning after the fire. In finding the search violative of the Fourth Amendment, the court stated that "the purpose of the Deputy Fire Marshal's investigation after 1 a.m. was to find evidence of a crime.[156] The *People* did not show any 'grave emergency' which justified not obtaining a search warrant.[157] There was no showing that in the time period between 1 a.m. and 9 a.m., when the investigation began in earnest, they could not have obtained a search warrant."[158]

In *People* v. *Zeisler*[159] the Appellate Court of Illinois reviewed a search that occurred approximately 12 hours after an initial examination failed to reveal the cause of the fire. The 12-hour delay occurred when the local investigator, who could not determine the cause of the fire, called in a Deputy Fire Marshal to assist in the investigation. In upholding the subsequent search, the court noted that the suspension of the investigation for several hours for the arrival of an expert was no different than postponing a search until the smoke clears or the proper tools become available.[160] The court determined that when the initial investigator called for assistance of the Deputy Fire Marshal, he did not suspect arson.[161] The court felt that had the initial investigator suspected arson when he re-entered the location, the entry might well have exceeded the boundaries of the Fourth Amendment in the absence of a warrant.[162]

In *Waters* v. *State*[163] the Court of Appeals of Georgia reviewed an investigation that began 4 hours after suppression of the fire. The Assistant Fire Chief testified that his suspicions as to the cause of the fire were aroused when he noticed that the fire was hotter than normal and that it took longer to extinguish than expected. Finally, the Assistant Fire Chief stated his suspicions were aroused because when he looked in the refrigerator, he saw that it was almost empty and he felt that this was indicative of an arson fire. In upholding the search, the court found that the search was done as soon as safety permitted and while the firefighters remained on the scene with a charged hose line to suppress any rekindle of the fire.[164]

However, the dissent in the case raised a legitimate concern about the examination of the refrigerator. The dissent noted that the Assistant Fire Chief testified that he always looked in the refrigerator when he was suspicious of the cause of the fire, because he felt an empty refrigerator was an indicator of arson.[165] The dissent, therefore, determined that the examination of the refrigerator was a search to gather evidence of criminal activity and not an examination to determine the cause and origin of the fire.[166] Therefore, the dissent determined that the search was in violation of the Fourth Amendment.[167]

In *State* v. *Harris*[168] the Missouri Court of Appeals reviewed an investigation that began after firefighters observed four unrelated fires in the location and immediately became suspicious of the origin of the fire. In upholding the search, the court noted that the investigators arrived 45 minutes after the suppression was completed and while the firefighters were still cleaning up the location.[169] The court held that the investigators were on the scene no more than 3 to 4 hours investigating the cause of the suspicious fire and all the evidence seized was in plain view.[170]

In *People* v. *Calhoun*[171] the New York Appellate Department reviewed an investigation that began 4 hours after firefighters had left the location. In upholding the search of the location, the court noted that while arson was suspected by the firefighters, the investigators were not told in advance that evidence of arson existed.[172] The court determined that while arson was a possible cause for the fire, "a spectrum of other imaginable causes, both natural and accidental, remained theories to be tested by the marshals."[173] Thus, since the search of the location was not motivated primarily by an intent to gather evidence to support an arson prosecution, the warrantless intrusion did not exceed the bounds of the emergency exception.[174]

Just as with the question of exigency, it is evident that various courts have reached divergent opinions on similar facts. Therefore, it is imperative that an investigator be familiar with his or her jurisdiction's case law on the impact of the suspicion of arson and origin and cause investigations. Many jurisdictions will suppress all evidence obtained once there is a suspicion of arson, and obviously, such a result can have a disastrous effect upon the ability to prosecute the owner or occupant of a location for an arson fire at the location.

SCOPE OF SEARCH

As the Court noted in *Clifford*, the scope of a search is limited to that area reasonably necessary to determine where and how the fire originated.[175] While the Court in *Clifford* took a very narrow approach to the scope of an origin and cause investigation, subsequent courts have not been so narrow in their approach.[176] However, an investigator must be aware that depending on the facts of a case, he or she may be precluded from conducting an investigation that moves from the most to the least burn, and may be required to go directly to the apparent area of origin to conduct an investigation.

In *State* v. *Monosso*[177] the Wisconsin Supreme Court examined the constitutionality of an investigation of an entire building when the fire had been contained to an office in the subbasement of the location. The court noted that firefighters engaged in normal firefighting tactics during the suppression of the fire, and that this included an examination of every room and closet in the location for the sole purpose of locating and rescuing any individuals in the location.[178] In determining that the search of the entire

building was appropriate, the court noted that the entire building had to be viewed in order for the investigators to properly rule out all accidental causes for the blaze.[179] The court found that if fire officials were limited to examining only those portions of the location directly damaged by direct fire impingement " ... it would render fire officials incapable of carrying out their duty to establish the cause of fires."[180] In order to fully investigate all possible causes, fire officials must be allowed access to an entire building for a reasonable period of time to facilitate the determination of the cause.[181] Therefore, the court upheld the investigator's entry into, and photographing of, the defendant's office which had suffered only smoke and heat damage.[182]

In *Cleaver* v. *Superior Court*[183] the California Supreme Court examined several searches of a fire-damaged basement that were admittedly conducted to look for physical evidence relating to a shoot-out with police.[184] In upholding the search, the court noted that " ... 'exigent circumstances means an emergency situation requiring swift action to prevent imminent danger to life or serious damage to property, or to forestall the imminent escape of a suspect or destruction of evidence'."[185] The court noted that in *Tyler* one of the Supreme Court's rationales for justifying a prompt determination of a fire's origin was that such immediacy might be necessary to preserve evidence from intentional or accidental destruction.[186] The court, thus, determined that since a warrantless search to preserve evidence from possible destruction is entirely proper, if conducted under exigent circumstances and the search for evidence was only the "primary reason"[187] for the search, that the searches were permissible.[188] The court held that "[s]ince the officers had a conceded right to conduct a full and complete inspection of the basement at 11:30 p.m., we conclude that the subsequent searches of these same premises, occurring within a reasonable time thereafter and based upon a continued state of exigent circumstances, were reasonable ..."[189]

ABANDONMENT

One area that the courts have infrequently examined is the question of the abandonment of a fire-damaged premises by the owner of the property. Many of the reasons for the infrequency of this issue may be the strong language that the Supreme Court used in rejecting the abandonment argument put forth in the *Tyler* case. In rejecting the government's argument that Tyler and Tompkins had abandoned the property by setting the fire at the premises, the Court noted that an assertion that innocent fire victims have no protectable expectations of privacy in whatever remains of their property was contrary to common experience.[190] The Court found that "[p]eople may go on living in their homes or working in their offices after a fire. Even when that is impossible, private effects often remain on the fire-damaged premises."[191] Finally, the Court held that it would be inappropriate for the Court to validate the introduction of evidence seized in a warrantless search based upon an arson that had not been proved at the time of the search, and a conviction obtained through the use of the evidence seized.[192] Thus, the Court perfunctorily rejected the government's attempt to assert that the owner of the premises had abandoned the premises by setting the arson fire. While the *Tyler* Court rejected the government's abandonment argument, other courts have upheld the government's abandonment argument when it was based on factors other than the setting of the fire by the owner of the premises.

In *State* v. *Lowther*[193] the South Dakota Supreme Court examined the defendant's challenge to an origin and cause investigation at two mobile homes that were destroyed by fire. In upholding the searches, the court relied on the United States Supreme Court's opinion in *Clifford*, and noted that "there is no indication that the defendant made any attempt to secure his fire-damaged mobile home."[194] The court went on to find that there was no indication that the defendant intended to continue to use the premises, but rather his conduct indicated an intent to abandon the property.[195] Based on these conclusions, the court found that the defendant did not exhibit a reasonable expectation in the property destroyed by the fire.[196]

In *People* v. *Remiro*[197] the California Court of Appeal reviewed a challenge to an origin and cause investigation at a rental unit that the defendants had occupied. In upholding the search, the court determined that the owner of the premises had taken possession of the property and consented to the search by the law enforcement officers.[198] The court noted that "[a]bandoned property is subject to search and seizure without a warrant"[199] and that the owner of the premises may consent to a search of premises that have been abandoned by the tenant.[200] The court, thus, distinguished the facts from those in *Michigan* v. *Tyler* by finding that the law enforcement officers were not basing their finding of abandonment solely upon evidence of arson acquired from their own investigation, but rather upon the owner's determination that his tenants abandoned the property.[201] While the court declined to rule on the legal sufficiency of the owner's determination,[202] the court noted that the determination was based upon

the belief that the tenants had, themselves, unlawfully fired the location and then fled the location at a rapid speed.[203] The court stated that this information was based upon information from private citizens who had observed the conduct and the firefighters who were lawfully in the house to extinguish the blaze.[204]

Therefore, it is evident from a careful reading of *Tyler* and a close examination of abandonment cases,[205] that the possibility of establishing an abandonment by arson still exists. While in most cases, abandonment will not be available to justify an entry to conduct an origin and cause investigation, the investigator should always carefully examine the events surrounding the fire and entry to determine the applicability of the doctrine to the existing facts. Once an abandonment of the premises is established, the defendant will be unable to suppress any evidence that was obtained as a result of a search of the location.

CONCLUSION

The confusion created by the lack of clarity in the *Tyler* and *Clifford* decisions is a veritable mine field for the arson investigator. Whenever he or she is conducting an investigation, all potential difficulties must be examined. What may seem insignificant at the time of a search may turn out to be the crucial factor in the defendant's motion to suppress evidence. Therefore, it is imperative that the investigator thoroughly document all of the activities during the fire suppression as well as during the origin and cause investigation. If the investigator can thoroughly document the law enforcement activities during suppression and investigation of a fire, he or she will be in a much better position to understand and justify the legal ramifications of the investigation. Finally, if the investigator can document and explain the activities during the suppression and investigation of a fire, the prosecutor and judge will be in a better position to uphold the constitutionality of the activities.

NOTES

[1] *Michigan* v. *Tyler* 436 U.S. 499, 98 S. Ct. 1942, 56 L. Ed. 2d 486 (1978); *Michigan* v. *Clifford* 464 U.S. 287, 104 S. Ct. 641, 78 L. Ed. 2d 477 (1984).

[2] 436 U.S. at 504, 98 S. Ct. at 1947.

[3] 436 U.S. at 505, 98 S. Ct. at 1947. See also: *See* v. *City of Seattle* (1967) 387 U.S. 541, 87 S. Ct. 1737, 18 L. Ed. 2d 943; *Marshall* v. *Barlow's Inc.* (1978) 436 U.S. 307, 98 S. Ct. 1816, 56 L. Ed. 2d 305.

[4] 436 U.S. at 506, 98 S. Ct. at 1948.

[5] *Tyler*, 436 U.S. at 506, 98 S. Ct. at 1948; *Clifford*, 464 U.S. at 293, 104 S. Ct. at 646.

[6] 436 U.S. at 508, 98 S. Ct. at 1949.

[7] *Clifford*, 464 U.S. at 292, 104 S. Ct. at 646; *Tyler*, 436 U.S. at 506, 98 S. Ct. at 1948.

[8] 436 U.S. at 509, 98 S. Ct. at 1949.

[9] 436 U.S. at 509, 98 S. Ct. at 1950.

[10] 436 U.S. at 509, 98 S. Ct. at 1950.

[11] 436 U.S. at 509, 98 S. Ct. at 1950.

[12] 436 U.S. at 510, 98 S. Ct. at 1950.

[13] *Clifford*, 464 U.S. at 306, 104 S. Ct. at 653.

[14] 436 U.S. 499, 98 S. Ct. 1942, 56 L. Ed. 2d 486 (1978).

[15] 436 U.S. at 509, 98 S. Ct. at 1950.

[16] 436 U.S. at 509, 98 S. Ct. at 1950.

[17] 436 U.S. at 510, 98 S. Ct. at 1950.

[18] 436 U.S. at 510, 98 S. Ct. at 1950.

[19] 436 U.S. at 510, 98 S. Ct. at 1950.

[20] 436 U.S. at 512, 98 S. Ct. at 1951. It is the writer's opinion that this "further access" language is the issue that has generated the greatest amount of confusion.

[21] 710 F. 2d 276 (1983).

[22] 710 F. 2d at 280. The Supreme Court's recent grant of certiorari was for *Michigan* v. *Clifford*.

[23] 464 U.S. 287, 104 S. Ct. 641, 78 L. Ed. 2d 477 (1984).

[24] 464 U.S. 287, 104 S. Ct. 641, 78 L. Ed. 2d 477 (1984).

[25] When no single rationale is endorsed by a majority of the Court, "the holding of the Court may be viewed as the position taken by those Members who concurred in the judgments on the narrowest grounds ..." *Gregg* v. *Georgia*, 428 U.S. 153, 169 n. 15, 96 S. Ct. 2909, 2923 n. 15, 49 L. Ed. 2d 859 (1976); *Marks* v. *United States*, 430 U.S. 188, 193, 97 S. Ct.

990, 993 51 L. Ed. 2d 260 (1977). It is the writer's opinion that the narrowest gro:..ds in the *Clifford* opinion is difficult to determine and the only agreement between the plurality opinion and the concurring opinion is that the conviction should be overturned based on an illegal search conducted in violation of the holding in *Tyler*.

[26] 464 U.S. at 291, 104 S. Ct. at 646. See, *e.g.*, *Donovan* v. *Dewey*, (1981) 452 U.S. 594, 101 S. Ct. 2534, 69 L. Ed. 2d 262; *United States* v. *Biswell*, (1972) 406 U.S. 311, 92 S. Ct. 1593, 32 L. Ed. 2d 87; *Colonnade* v. *United States*, (1970) 397 U.S. 72, 90 S. Ct. 774, 25 L. Ed. 2d 60.

[27] 464 U.S. at 292, 104 S. Ct. at 646.

[28] 464 U.S. at 292, 104 S. Ct. at 646.

[29] 464 U.S. at 296, 104 S. Ct. at 648.

[30] 464 U.S. at 296, 104 S. Ct. at 648.

[31] 464 U.S. at 296, 104 S. Ct. at 648.

[32] 464 U.S. at 293, 104 S. Ct. at 646.

[33] 464 U.S. at 292, 104 S. Ct. at 646.

[34] 464 U.S. at 292-3, 104 S. Ct. at 646.

[35] 464 U.S. at 293, 104 S. Ct. at 647.

[36] 464 U.S. at 292, 104 S. Ct. at 646.

[37] While the Court's opinion does allow for investigation of a fire scene during suppression activities, the Court requires any additional investigation be done after the fire is suppressed and fire and police officials have left the location to be conducted pursuant to a warrant or a new exigency. 464 U.S. at 293, 104 S. Ct. at 647. Since it is unclear as to what will be deemed a reasonable time to investigate after suppression of the fire, the Court's opinion probably requires a warrant after suppression is completed.

[38] 464 U.S. at 294, 104 S. Ct. at 647. This type of language seems to reflect that the plurality would require a warrant to search for the evidence of a crime even when the exigency of suppression exists. While the writer believes that this position would not be upheld by the present Supreme Court, he is aware that some prosecutors do require a warrant under such circumstances. See, *United States* v. *Urban* 710 F. 2d 276, 279 (6th Cir. 1983). (Investigators subjective intention does not control the issue of exigency.) Interestingly, an examination of the facts of *Tyler* reveals that when the investigators left the location they had already concluded that the fire "could possibly have been arson." *Tyler* 436 U.S. at 502, 98 S. Ct. 1946.

[39] This conclusion is a very complex determination and probably should not be made by an investigator.

[40] Unfortunately, not all states allow for administrative warrants. In addition, the Judges in many states do not understand the administrative warrant procedures.

[41] 464 U.S. at 299, 104 S. Ct. at 650.

[42] 464 U.S. at 299, 104 S. Ct. at 650.

[43] 464 U.S. at 300, 104 S. Ct. at 650.

[44] 464 U.S. at 301, 104 S. Ct. at 650.

[45] 464 U.S. at 301, 104 S. Ct. at 651, quoting *Michigan* v. *Tyler*, 436 U.S. at 516, Justice White concurring in part, dissenting in part.

[46] 464 U.S. at 303, 104 S. Ct. at 652.

[47] 464 U.S. at 303, 104 S. Ct. at 652.

[48] 464 U.S. at 303, 104 S. Ct. at 652.

[49] 464 U.S. at 305, 104 S. Ct. at 653.

[50] However, since each of the opinions approach the factual and legal issues in this case from a different direction, the opinions are not easily synthesized into any commonality.

[51] 464 U.S. at 306, 104 S. Ct. at 653.

[52] 464 U.S. at 306, 104 S. Ct. at 653.

[53] 464 U.S. at 310, 104 S. Ct. at 655.

[54] 464 U.S. at 310, 104 S. Ct. at 655.

[55] 464 U.S. at 309, 104 S. Ct. at 655.

[56] 464 U.S. at 310, 104 S. Ct. at 655.

[57] 464 U.S. at 309, 104 S. Ct. at 655.

[58] 464 U.S. at 309, 104 S. Ct. at 655.

[59] Due to the confusion in the Court's opinions, the issue as to when and what type of warrant an investigator needs under a given case can only be determined on a case-by-case basis. In the writer's opinion, as long as an investigation is conducted in a reasonably timely manner and is only for the purposes of determining the cause of a fire, there is no need for a warrant. Therefore, the purpose of this section is merely to provide the general guidelines of the warrant requirements under the assumption that the investigation was not begun in a reasonably timely fashion.

[60] *Tyler*, 436 U.S. at 508, 98 S. Ct. at 1949.

[61] 464 U.S. at 294, 104 S. Ct. at 647.

[62] 464 U.S. at 294, 104 S. Ct. at 647.

[63] As compared to and based on broad legislative and regulatory guidelines. A nonprogramatic warrant is normally prepared in response to specific events.

[64] 464 U.S. at 292, 104 S. Ct. at 646.

[65] 464 U.S. at 294, 104 S. Ct. at 647.

[66] 464 U.S. at 294, 104 S. Ct. at 647.

[67] 464 U.S. at 294, 104 S. Ct. at 647.

[68] 464 U.S. at 294, 104 S. Ct. at 647.

[69] 464 U.S. at 294, 104 S. Ct. at 647. See also: *Andresen* v. *Maryland* 427 U.S. 463, 96 S. Ct. 2737, 49 L. Ed. 2d 627 (1976); *United States* v. *Johnson* 690 F. 2d 60 (3rd Cir. 1982).

[70] 466 U.S. 740, 104 S. Ct. 2091, 80 L. Ed. 2d 732 (1984). See also: *Payton* v. *New York*, 445 U.S. 573, 100 S. Ct. 1371, 63 L. Ed. 2d 629 (1980).

[71] 466 U.S. at 749, 104 S. Ct. 2097.

[72] *Tyler*, 436 U.S. at 509, 98 S. Ct. at 1949; *Clifford*, 464 U.S. at 294, 104 S. Ct. 647.

[73] *Tyler*, 436 U.S. at 509, 98 S. Ct. at 1949; *Clifford*, 464 U.S. at 294, 104 S. Ct. 647.

[74] As Justice Rehnquist noted, in reference to the reasonableness of the investigation delay in *Clifford*, 464 U.S. at 309, n. 1, 104 S. Ct. at 655, n. 1.

[75] *Mincey* v. *Arizona*, 437 U.S. 385, 392, 98 S. Ct. 2408, 2413, 57 L. Ed. 2d 46 (1984); *United States* v. *McConney*, 728 F. 2d 1195, 1199 (9th Cir. 1984); *United States* v. *Echegoyen* 799 F. 2d 1271, 1278 (9th Cir. 1978).

[76] *Tyler* 436 U.S. at 510, 98 S. Ct. at 1950; *Clifford* 464 U.S. at 293, 104 S. Ct. 646-47.

[77] 843 F. 2d 401 (9th Cir. 1988)

[78] 843 F. 2d at 403.

[79] 843 F. 2d at 404.

[80] 843 F. 2d at 404.

[81] 8 Cal. App. 3d 392, 87 Cal. Rptr. 280 (1970).

[82] 8 Cal. App. 3d at 396.

[83] 8 Cal. App. 3d at 396-97.

[84] 8 Cal. App. 3d at 397.

[85] 8 Cal App. 3d at 396.

[86] 86 Ill. 2d 78, 426 N. E. 2d 871 (Ill. 1981).

[87] *Holloway*, 426 N. E. 2d at 875.

[88] *Holloway*, 426 N. E. 2d at 875.

[89] *Holloway*, 426 N. E. 2d at 875.

[90] *Holloway*, 426 N. E. 2d at 875.

[91] *Holloway*, 426 N. E. 2d at 875.

[92] 49 N.Y. 2d 398, 402 N. E. 2d 1145 (1980).

[93] *Holloway*, 426 N. E. 2d at 876.

[94] *Holloway*, 426 N. E. 2d at 877.

[95] 286 N. W. 2d 163 (Iowa, 1979).

[96] 286 N. W. 2d at 167.

[97] 286 N. W. 2d at 167.

[98] 419 A. 2d 917 (Del. 1980).

[99] 419 A. 2d at 923.

[100] 449 A. 2d 192 (Del. 1982).

[101] 449 A. 2d at 194.

[102] 449 A. 2d at 194.

[103] 449 A. 2d at 194-5.

[104] 607 F. 2d 559 (2nd Cir. 1979).

[105] 607 F. 2d at 564.

[106] 607 F. 2d at 564. See also: *United States* v. *Urban* 710 F. 2d 276 (6th Cir. 1983).

[107] 588 F. 2d 882 (3rd Cir. 1978).

[108] 588 F. 2d at 892.

[109] 588 F. 2d at 892.

[110] 588 F. 2d at 892.

[111] 282 N. W. 2d 528 (Minn. 1979).

[112] 282 N. W. 2d at 531.

[113] 282 N. W. 2d at 531.

[114] 282 N. W. 2d at 531.

[115] 282 N. W. 2d at 531.

[116] 282 N. W. 2d at 531 (quoting *Tyler*, 436 U.S. at 510, 98 S. Ct. at 1950).

[117] 282 N. W. 2d at 532.

[118] 282 N. W. 2d at 532.

[119] 840 S. W. 2d 480 (Tex. App. 1992).

[120] 840 S. W. 2d at 487.

[121] 840 S. W. 2d at 487 (quoting *Clifford*, 464 U.S. at 292, 104 S. Ct. at 646).

[122] 840 S. W. 2d at 487.

[123] 308 S. E. 2d 445 (N.C. App. 1983).

[124] 308 S. E. 2d at 448.

[125] 449 So. 2d 196 (La. App. 3rd Cir. 1984).

[126] 449 So. 2d at 197.

[127] 449 So. 2d at 199.

[128] 449 So. 2d at 199.

[129] 449 So. 2d at 200.

[130] 449 So. 2d at 200.

[131] 449 So. 2d at 199-200.

[132] 449 So. 2d at 200.

[133] 449 So. 2d at 199.

[134] 449 So. 2d at 199.

[135] 203 Cal. App. 3d 1517, 251 Cal. Rptr. 36 (1988).

[136] 203 Cal. App. 3d at 1521.

[137] 203 Cal. App. 3d at 1521.

[138] 203 Cal. App. 3d at 1522.

[139] 203 Cal. App. 3d at 1523.

[140] 203 Cal. App. 3d at 1523.

[141] 209 Cal. App. 3d 836, 257 Cal. Rptr. 522 (1989).

[142] 209 Cal. App. 3d at 839.

[143] 474 F. 2d 1385 (5th Cir. 1973).

[144] 209 Cal. App. 3d at 836, quoting *Green*, 474 F. 2d 1390.

[145] 209 Cal. App. 3d at 845.

[146] 209 Cal. App. 3d at 845.

[147] For additional cases on warrantless, nonconsensual searches see: *United States* v. *Clark* 617 F. Supp. 693 (D.C. Pa. 1985); *United States* v. *Hoffman* 607 F. 2d 280 (9th Cir. 1979); *United States* v. *Martin* 781 F. 2d 671 (9th Cir. 1985); *United States* v. *Metzger* 778 F. 2d 1195 (6th Cir. 1985); *State* v. *York* 463 N. W. 2d 705 (Iowa App. 1990).

[148] *Clifford*, 464 U.S. at 294, 104 S. Ct. 647.

[149] 148 N. E. 2d 547 (Ind. 1958).

[150] 148 N. E. 2d at 551.

[151] 148 N. E. 2d at 548.

[152] 148 N. E. 2d at 551.

[153] 148 N. E. 2d at 548.

[154] 131 Mich. App. 21, 345 N. W. 2d 637 (Mich. 1983).

[155] Amazingly, the facts in this case are strikingly similar to the *Tyler* case, but the result is inapposite.

[156] The fire was not completely suppressed until approximately 3:00 a.m. Therefore, the court suppressed evidence that was obtained during suppression activities.

[157] *Rammouni,* 345 N. W. 2d at 638.

[158] *Rammouni,* 345 N. W. 2d at 638.

[159] 112 Ill. App. 3d 788, 445 N. E. 2d 1324 (Ill. App. 3rd Dist. 1983).

[160] *Zeisler,* 445 N. E. 2d at 1328.

[161] *Zeisler,* 445 N. E. 2d at 1328.

[162] *Zeisler,* 445 N. E. 2d at 1328.

[163] 174 Ga. App. 916, 331 S. E. 2d 893 (Ga. App. 1985).

[164] *Waters,* 331 S. E. 2d at 895.

[165] *Waters,* 331 S. E. 2d at 895.

[166] *Waters,* 331 S. E. 2d at 895.

[167] *Waters,* 331 S. E. 2d at 895.

[168] 639 S. W. 2d 122 (Mo. App. 1985).

[169] 639 S. W. 2d at 124.

[170] 639 S. W. 2d at 124.

[171] 49 N.Y. 2d 398, 402 N. E. 2d 1145 (1980).

[172] *Calhoun,* 402 N. E. 2d at 1149.

[173] *Calhoun,* 402 N. E. 2d at 1149.

[174] *Calhoun,* 402 N. E. 2d at 1149.

[175] *Clifford,* 464 U.S. 298, 104 S. Ct. 649.

[176] See: *State* v. *Newcome* 41 Ohio App. 3d 51, 534 N. E. 2d 370 (Ohio App. 1987); *State* v. *Wilson-Bey* 21 Conn. App. 162, 572 A. 2d 372 (Conn. App. 1990).

[177] 103 Wis. 368, 308 N. W. 2d 891 (1981).

[178] *Monosso* 308 N. W. 2d at 893.

[179] *Monosso* 308 N. W. 2d at 895.

[180] *Monosso* 308 N. W. 2d at 895.

[181] *Monosso* 308 N. W. 2d at 895.

[182] *Monosso* 308 N. W. 2d at 895.

[183] 24 Cal. 3d 297, 155 Cal. Rptr. 559, 594 P. 2d 984 (1979).

[184] 24 Cal. 3d at 301. The *Cleaver* is an aberration in California today since the defendant would no longer have vicarious standing to challenge the searches.

[185] 24 Cal. 3d at 302.

[186] 24 Cal. 3d at 304.

[187] The investigators were also conducting origin and cause investigations.

[188] 24 Cal. 3d at 306.

[189] 24 Cal. 3d at 303.

[190] *Tyler,* 436 U.S. at 505, 98 S. Ct. at 1948.

[191] *Tyler,* 436 U.S. at 505, 98 S. Ct. at 1948.

[192] *Tyler,* 436 U.S. at 506, 98 S. Ct. at 1948.

[193] 434 N. W. 2d 747 (S.D. 1989).

[194] 434 N. W. 2d at 755.

[195] 434 N. W. 2d at 755.

[196] 434 N. W. 2d at 755.

[197] 89 Cal. App. 3d 809, 153 Cal. Rptr. 89.

[198] 89 Cal. App. 3d at 833.

[199] 89 Cal. App. 3d at 833.

[200] 89 Cal. App. 3d at 834.

[201] 89 Cal. App. 3d at 834.

[202] 89 Cal. App. 3d at 834.

[203] 89 Cal. App. 3d at 834.

[204] 89 Cal. App. 3d at 834.

[205] See also: *United States* v. *Callabrass* 607 F. 2d 559 (2nd Cir. 1979); *United States* v. *Miller* 589 F. 2d 1117 (1st Cir. 1978); *United States* v. *Oswald* 783 F. 2d 663 (6th Cir. 1986); *United States* v. *Tolbert* 517 F. Supp. 1081 (E. D. Mich. 1981).

Section II
Extended Abstracts

Sect of the Solar Temple - Suicides and Collective Murders of 48 Persons in Switzerland on October 4-5, 1994 - Use of Remote Telecontrol Fire Setting Systems to Destroy Sites Successively, But Geographically Far Apart

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The geographical situation was as follows:

- There were 22 people in Cheiry at an isolated farm.
- There were 26 people in Salvan at two chalets close to each other, but 100 km away from the farm (Cheiry).
- There was a chalet, a wooded shelter, and a garage situated in Salvan (all unoccupied), as well as 4 vehicles approximately 500 meters away from the aforementioned buildings.
- There was an empty flat situated in Montreux approximately an equal distance from Cheiry and Salvan.
- There was an unoccupied house situated in Aubignan, France, at a distance of approximately 400 km from the Swiss border.

The investigation of the three Swiss sites has allowed reconstruction of the fire setting systems and experimentation with them. Some telecontrols fulfilled their role; cadavers and buildings were badly burned. Other telecontrols functioned, but did not transmit the fire to their target; only one was discovered intact. The whole fire setting mechanism was constructed of:

- A 12-volt telecommand which could be switched on from anywhere in the world by telephone communication; and

- A 12/220-volt relay, activated by command, which could open or close a circuit feeding 2 lines with a clock and a heater whose resistances had been bared and an electrovalve linked to one or two bottles of propane gas.

Anticipated functioning mode:

- A telephone call would switch on the relay through the telecommand; the 220-volt circuit was closed. The electrovalve opened and the gas poured out in rooms whose openings had been clogged.

- The clock was put under tension; at the programmed time, the heater was switched on above a vessel containing gasoline. A few seconds later, matches or firelighters fastened to the heating resistances burst into flames and transmitted the fire to fuel vapors as well as to the gas layer liberated by the electrovalve.

CHEIRY

Two lines, activated by telecommand, switched on either manually or at half past eleven from Salvan:

- At the ground floor, a clock was linked to a heater with gasoline and an electrovalve with two bottles of propane gas.

- Upstairs, a clock was linked to a heater with gasoline.

The whole first floor was destroyed. The fire cut the line feeding the device installed at the ground floor which, thereby, remained undamaged.

SALVAN

Two chalets were connected; one contained the telecommand feeding. At each ground floor, one electrovalve with two bottles of propane gas and a clock were linked to a heater with gasoline. At each floor, a clock was programmed to switch on a heater with gasoline at three o'clock.

In each building, the ground floor was badly burned and an explosion occurred in the heating room. The first floor, where the telecommand was installed, had vanished. On the first floor of the second chalet, only the gasoline vapors had burned.

At a quarter to three the third chalet, the wooded shelter, the garage, and four vehicles were set on fire through a heater which was activated manually. In the shelter, the heater failed to ignite the gasoline vapors whereas the chalet, the garage, and the vehicles were entirely destroyed.

MONTREUX

The telecommand, very probably activated from Salvan at exactly nineteen minutes past midnight, switched on an electrovalve and a clock which was linked to a heater. The matches burst into flames and transmitted the fire to the gas which burned without explosion and without setting fire to the flat.

AUBIGNAN

Investigations have been done by the French Police. The telecommand, very probably activated from Salvan at seventeen minutes past midnight, switched on both the electrovalve and the clock. Like in Montreux, the propane burned without explosion or fire.

CONCLUSION

The fire setting systems functioned, except for the ground floor at Cheiry, but never reached their purposes. The delayed fire setting system was miscalculated to enable an explosion of propane gas. The gas volume released by the electrovalve never reached the lower limit of explosibility (2, 4% propane in air). The clocks switched on the heater resistances too soon. It is probable that the conceptor of the system and the person who installed it in the various buildings were not the same. The leaders of the sect had planned a complete destruction without external intervention in order that no one would survive the apocalypse.

Alaskan Gasoline

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Automotive gasolines are complex mixtures of hydrocarbons derived from petroleum. These hydrocarbons are produced from fractional distillation of crude oil and from chemical conversion processes which are used to increase the amount and quality of the gasoline obtained. The hydrocarbons found in gasolines are dependent upon both the refinery practices and the crude oil used in manufacturing (Bolt and Hall 1977).

There are two refineries in the state of Alaska that produce gasoline: the Tesoro Alaska Petroleum refinery located in south central Alaska, and a refinery operated by Mapco Alaska Petroleum located in Alaska's interior. Only the Tesoro refinery produces a premium 92 octane gasoline. Both companies have exchange agreements for each other's products and supply gasoline to Alaskan service stations operated by other companies.

Gasoline samples obtained from California, North Carolina, and Alaska were diluted with carbon disulfide and run on a Hewlett-Packard 5890 Gas Chromatograph (Hewlett-Packard Company, Palo Alto, CA) equipped with a flame ionization detector and an HP-45 meter x 0.21 mm i. d. fused-silica capillary column coated with methyl silicone at a film thickness of 0.50 µm. The oven temperature was programmed as follows: initial temperature - 40°C, initial hold - 2.0 minutes, program rate - 20°C/minute, final temperature - 270°C. Significant differences were noted between the gasoline samples refined in Alaska and the samples from North Carolina and California. Chromatograms of Alaskan gasoline samples exhibit few components past the m-ethyltoluene/pseudocumene 5-peak group. Higher peak groupings characteristic of gasoline (ASTM 1994) such as 1- and 2-methylnaphthalene are not present. Recognizing these differences may provide valuable evidential information for arson investigators

CASE EXAMPLE

During one fire investigation, the North Carolina State Bureau of Investigation Crime Laboratory analyzed an accelerant thought to be a sample of gasoline from Alaska. This questioned sample was unlike the gasoline normally seen in North Carolina. Part of the sample was forwarded to the Alaska Scientific Crime Detection Laboratory for comparison with known Alaskan gasoline. The chromatogram of the unknown sample matched very closely with a known Alaskan gasoline standard. This supported the investigator's theory that the arsonist had brought the accelerant with him from Alaska.

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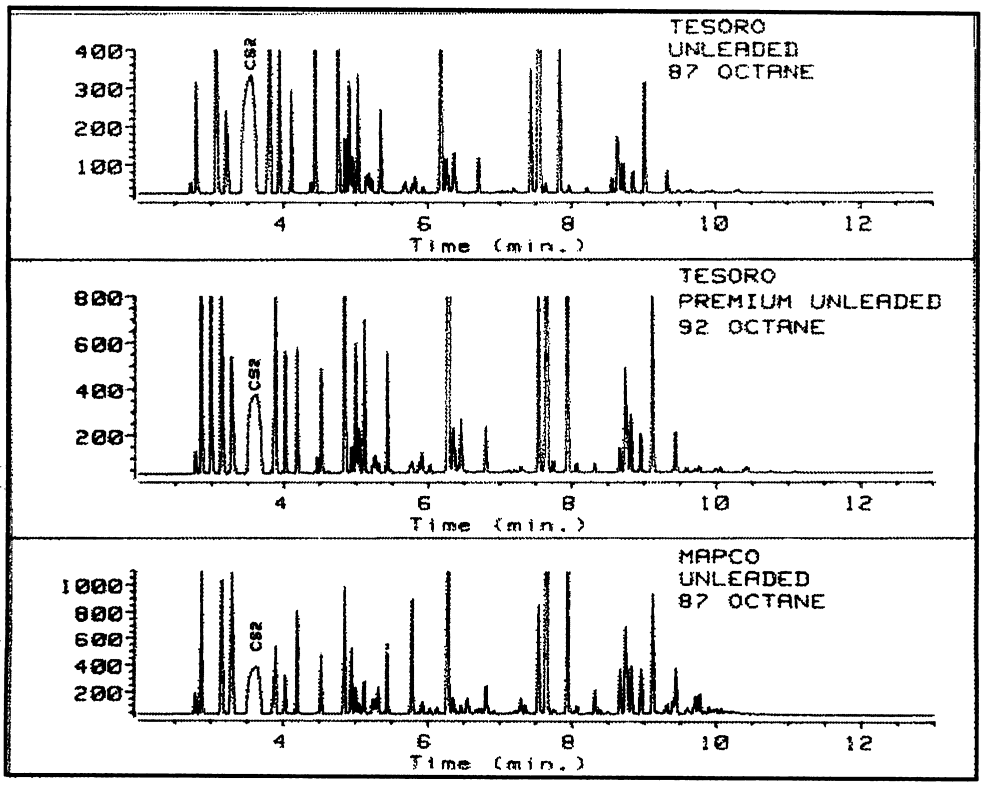

Figure 1. Chromatograms of gasoline refined in Alaska. Both Mapco and Tesoro supply 87 octane to other service stations. Tesoro is the sole source of 92 octane gasoline.

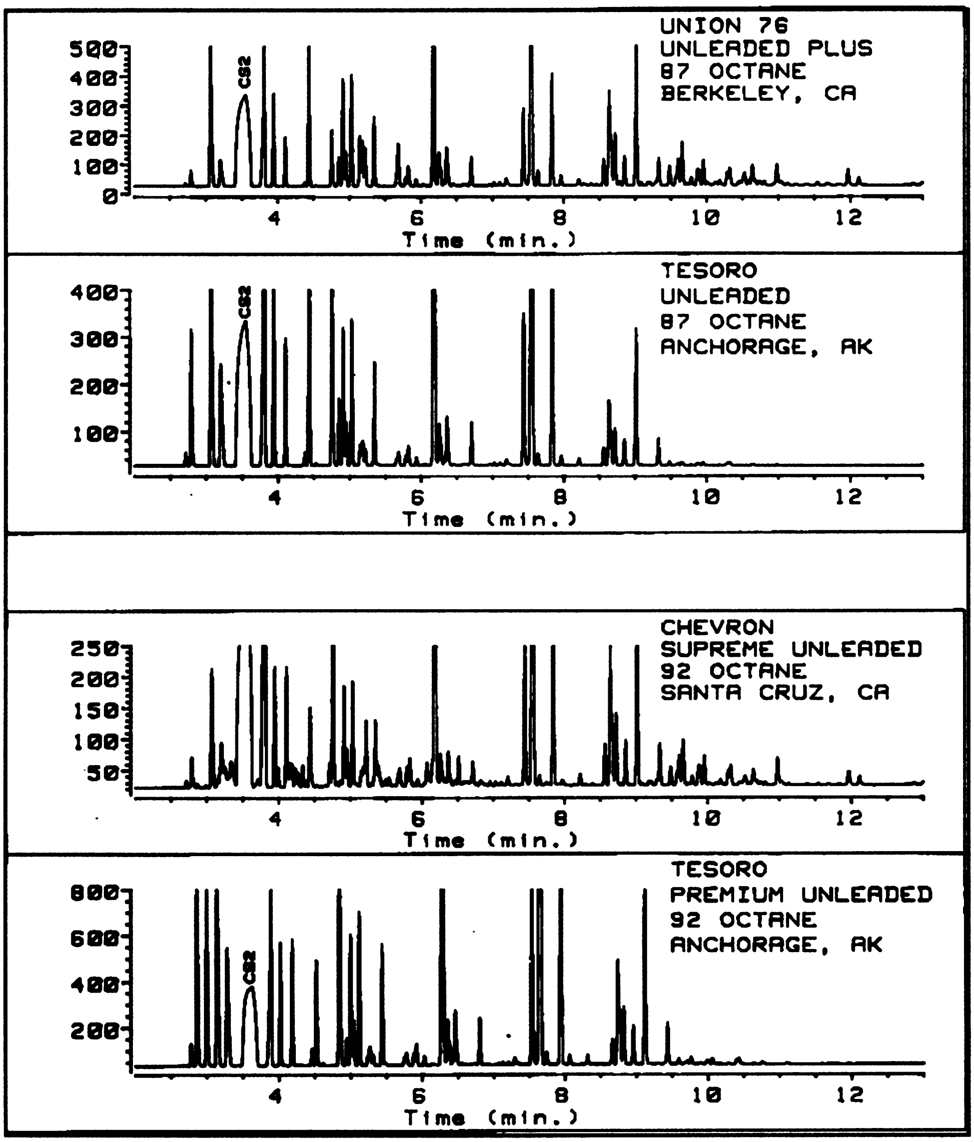

Figure 2. Chromatograms of Alaskan gasoline compared to gasoline from California.

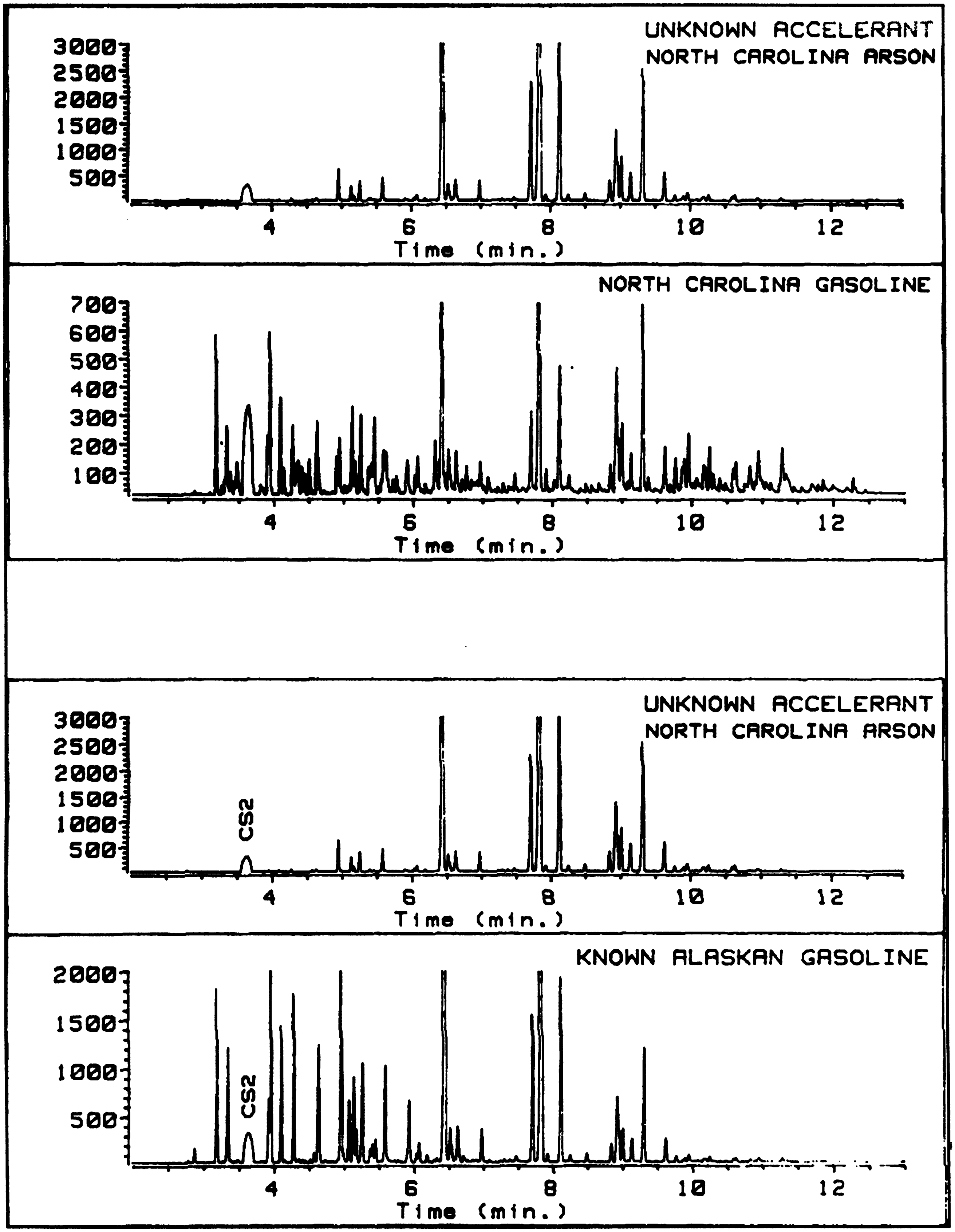

Figure 3. Case example.

The Potential for Self-Heating of Deep-Fried Food Products

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Tests were undertaken to help determine the cause of a restaurant fire. Although this was a simple fire with no serious injury or property damage, it was an apparent case of spontaneous combustion under circumstances in which such a cause had not to our knowledge been previously confirmed. The implications for other fire investigations and for safety recommendations were, therefore, very significant.

A cook had prepared three batches of a soft crumbly product used to make an East Indian confectionery. This has a texture and appearance similar to bread crumbs and is prepared from gram flour deep fried in canola (rape seed) oil. The cook placed the product in three large metal colanders and went home, leaving the hot oil to drain into saucepans. A fire was reported approximately 8 hours later by the owner of a neighboring business. Investigation showed the fire to have been centered on one of the three colanders. One of the remaining colanders, and the product contained in it, had not been seriously affected by the fire and was seized for laboratory examination, together with samples of what were said to have been the basic ingredients.

MATERIALS AND METHODS

Headspace analysis on samples from the scene confirmed the absence of petroleum products or other possible accelerants. Solvent extraction on the cooked product yielded a vegetable oil consistent with the expected canola oil. Its iodine value was 116 compared to 123 for the raw ingredient being used, values indicative of moderate unsaturation. A stainless steel bucket filled with the product was placed in a laboratory oven. The oven temperature was recorded together with that at three levels in the bucket; results are shown in Figure 1. With the oven turned on and closed, temperatures in the bucket went above that of the oven itself. When the oven was turned off and left open to allow free access of air, the temperature at the top of the bucket rose rapidly to nearly 330°C, producing considerable smoke and leaving a blackened, charred mass.

DISCUSSION

The potential for rags contaminated with drying oils such as linseed oil to undergo self-heating has been extensively studied. Much more recently, information has become available that rags contaminated with moderately unsaturated oils may self-heat to flaming combustion when a modest source of initial heating is available. Such oils include common vegetable oils such as corn and canola oil (Dixon 1994; Taylor and Seib 1991). Most of their work was done with cotton or cotton/polyester rags as the substrate material. The present investigation indicates that although self-heating remains an uncommon fire cause, the range of situations and substrate materials in which it can occur may be somewhat broader than was previously recognized.

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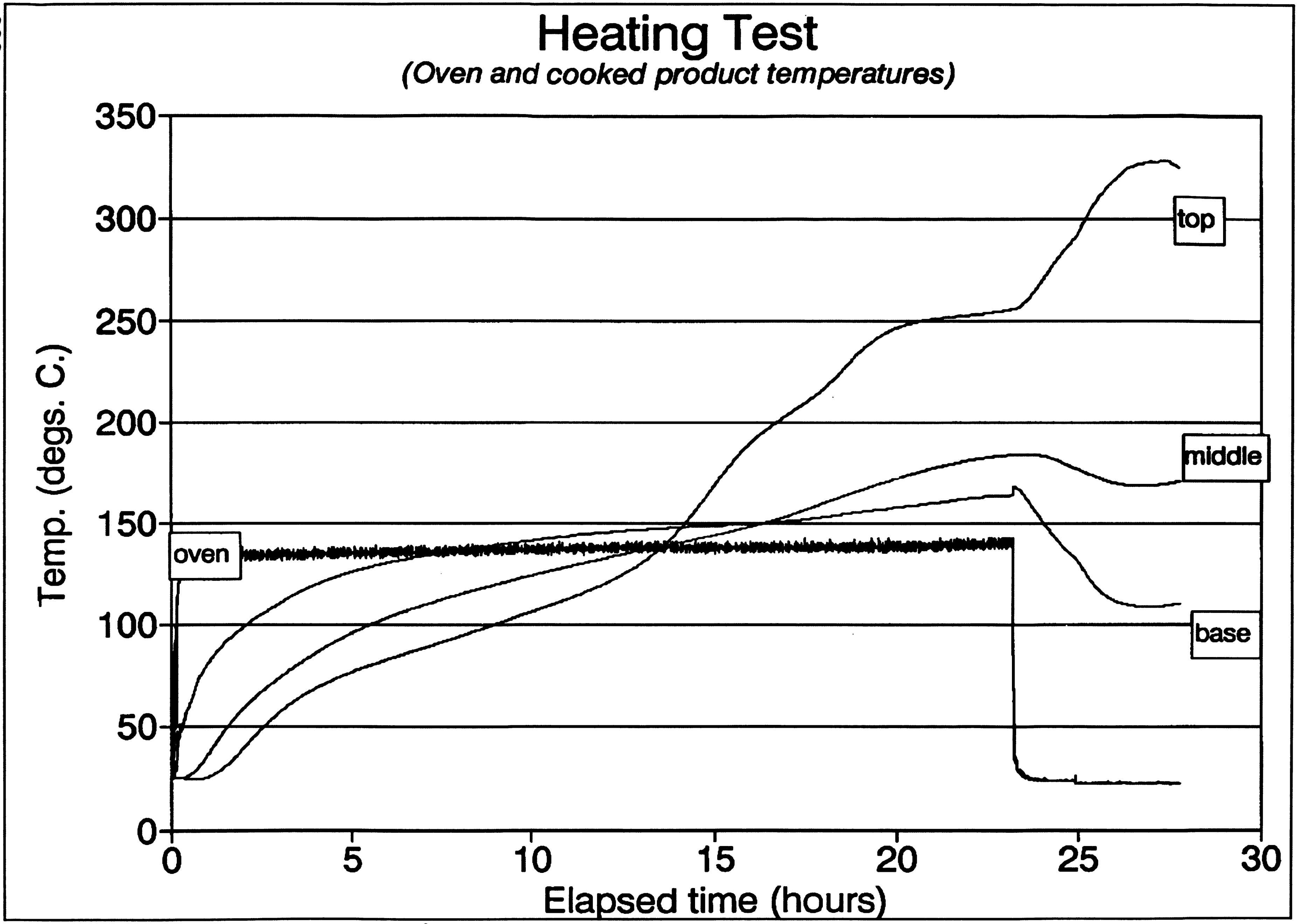

Figure 1. Oven temperature and temperatures within a bucket of heated Indian confectionery.

Accelerant Detection Canines as a Forensic Evidence Gathering Tool

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Many impulsive spite/revenge and poorly planned fraud fires are initiated and spread by utilizing readily available or easily obtainable flammable or combustible liquids. Weapons of choice are often hydrocarbon-based products such as gasoline, kerosene, fuel oil, paint thinners, and charcoal lighter fluids. Any of these products can be an effective accelerant (NFPA 1995) and may commonly be found in both residences and businesses.

The investigation of a fire scene where a hydrocarbon-based liquid has been used as an accelerant often reveals unusual burn patterns, witness accounts of rapid fire spread, and fire damage inconsistent with fuel loads. Temperatures within the fire area, at least during the early stages of the fire, are often higher than normal and most of the hydrocarbon-based liquid will be consumed leaving only trace amounts of heavily-weathered product in random protected areas. Accurate fire scene detection of residual accelerant is close to impossible by a human investigator without some type of adjunct detection equipment.

Mechanical or electronic "sniffers" detect hydrocarbon residue, but are nonselective and appear to indicate on many normally-present background materials. Maintenance, batteries, moisture, and contamination contribute to fire scene problems. Most electronic devices that are currently available, whether accurate or not, operate too slowly for practical use in a large fire scene.

The purpose of the Accelerant Detection Canine (ADC) is to quickly, and with a fair degree of accuracy, identify the locations of potential hydrocarbon-based accelerant residue. Fires involving one room or even large structures can be thoroughly searched in only a fraction of the time that would be spent by a human investigator attempting to locate the best spots for sampling.

The ADC's unique ability to scent discriminate further increases the odds of obtaining a "hot" sample for the laboratory. The ADC's level of detection sensitivity can be maintained on an equal plane with the forensic laboratory's level of detection and identification.

The ADC is a reasonably accurate tool intended simply to locate forensic evidence and is not a substitute for a thorough and systematic examination of a fire scene by expert investigators.

Positive responses by an ADC indicate locations where material is located that the ADC is trained to recognize. The ADC is not perfect and can be misled by some household products such as floor covering, adhesives, and petroleum-based pesticides that may leave residue similar to common accelerants. Samples should always be taken for analysis for a forensic chemist. Screening of samples at the fire scene by the ADC increases the probability of obtaining positive samples.

The combination of the ADC fire scene search and on-scene sample screening has increased the number of positive samples received at the laboratory from this agency from approximately 30% pre-ADC to the current 80% (Young's Laboratory, Bangor, ME, 1992). An additional benefit has been lower laboratory costs due to the decreased number of samples taken per fire investigation.

REFERENCES

NFPA 921. *Guide for Fire and Explosion Investigators.* National Fire Protection Association, Qunicy, MA, 1995.

The Connecticut State Police Canine Accelerant Detection Program - An Update and Analysis

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The Connecticut State Police Canine Accelerant Detection Program is in its 9th year. Currently, there are four dogs in the arson unit. With the retirement of Mattie (Connecticut's first arson dog) these dogs constitute the second generation of the K-9 program. For the period of July 1991 to April 1995, the laboratory has received approximately 1,102 K-9 alerts and has confirmed a positive response for 85.4 percent of these alerts. This percentage reflects the presence of identified substances which in our opinion can produce false positive responses by the dogs. In our experience, we have identified these types of compounds from a variety of sources. Some examples include: aromatic hydrocarbons from thermally-degraded polystyrene insulation and other polystyrene-containing polymers (*i.e.*, ABS plastics; alkyl substituted aromatics from cable oil used in electrical cables; alkyl substituted silicones from water repellent treatments for wood, concrete, and masonry; n-alkanes from pressure-treated lumber and polyalkyl polymers—polyethylene, polypropylene, etc.; branched-chain hydrocarbons and other alkyl compounds from laundry products, and terpenes and turpentine from thermally degraded "softwoods"). Compounds such as these which are formed as a result of the pyrolysis of natural and synthetic materials are considered positive responses when calculating a dog's statistics. This is done because, in our opinion, it is unfair to penalize the dog for alerting quite properly to compounds contained in possible accelerants.

The dogs are trained using 50 percent evaporated gasoline. However, they are able to "crossover" and alert to approximately 20 other types of flammable and/or combustible liquids. Although they do alert to substances not contained in the training tool, it has been our experience and that of the dog handlers that the dogs prefer the gasoline over all other possible choices. A preliminary study of the dog's response to compounds from each chemical class contained in gasoline indicates that the lower molecular weight aromatic hydrocarbons are the most successful at triggering an alert.

These observations are exemplified in a fatal fire case where an instrumental hydrocarbon "sniffer" was used to obtain evidence. Sixty-two items were submitted to the laboratory for analysis; subsequent examination by an arson dog reduced the number of likely accelerant-containing items to seven. These items were chosen despite the fact that almost all of the items contained large amounts of extraneous compounds such as branched-chain hydrocarbons.

The Importance of the K-9 Investigator and Fire Debris Chemist Relationship

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The relationship between K-9 investigators and arson chemists is a relationship that seems to have "gone to the dogs" in many areas. It is no wonder that this has happened since the two personality types involved tend to be diametrically opposed. On one side, there is the K-9 handler who generally has a lot of faith in his/her dog even before it has been tested completely. On the other side, you have a chemist who often will put little faith in anything before it has been subjected to strict scientific testing. Unless communication and cooperation between these two sides is open, a tension will normally build which can prove to be destructive to the entire program.

Having observed numerous K-9 teams, with and without chemists involved, the advantages of a good working relationship become obvious. Some of the advantages for the K-9 handler include gaining a hopefully unbiased outside source to help in setting up blind tests, keeping records of that testing, and testifying in court as to the reliability of that particular dog. The chemist will also develop a better respect for that dog's abilities and limitations. This will help in the interpretation of their results as well as aid in identifying any future problems so that they may be taken care of in a timely manner. Conversely, the chemist will also realize the limitations of their instrumentation when compared to the canine's olfactory senses. Time spent on cases will also generally go down for the chemist since fewer, and more often positive samples are submitted.

The benefits of creating a good working relationship between the K-9 handler and the fire debris chemist are numerous. Improving this rocky relationship rather than becoming adversaries will help to finely tune the accelerant canine into the best tool available for locating flammable liquids at a fire scene.

Statistical Data on the Examination of Arson Evidence in Indianapolis and Marion County From 1984 Through 1994

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The Indianapolis-Marion County Forensic Services Agency is charged with the mission of performing analysis upon fire debris samples submitted by the five municipal fire departments (Beech Grove Fire Department, Castleton Fire Department, Indianapolis Fire Department, Lawrence Fire Department, and Speedway Fire Department) and eight township fire departments (Decatur Township, Franklin Township, Lawrence Township, Perry Township, Pike Township, Warren Township, Washington Township, and Wayne Township) located throughout Marion County. These agencies are responsible for providing fire service and arson investigation for the 797,159 people living in Marion County (Indianapolis Department of Metropolitan Development, Planning, Division; Census Section, 317-327-5142). Laboratory case records for the period of January 1, 1983, to December 31, 1994, were examined and data from every suspected arson case was collected. In this 11-year period of time, 806 fire debris cases were analyzed by this laboratory. It was decided that looking at these cases may provide some information as to the problems and fire trends confronting a fire agency or forensic laboratory with regards to arson in a midwest metropolitan area.

METHODS OF ANALYSIS

All of the fire debris cases were analyzed using a Hewlett-Packard 5880A gas chromatograph with a flame ionization detector (Hewlett-Packard Company, San Fernando, CA). The chromatographic runs were made using the same column R+x(R)-1 30m, 0.32mm ID, 0.25 µm thickness crosslinked methyl silicone (Restek Corporation, Bellefonte, PA). The carrier gas was nitrogen, 3 mL/min found in Table 1. The flammable or combustible liquid residues were isolated from the fire debris using an absorption/ elution method of headspace concentration. For this method, activated charcoal was used as the absorbent and carbon disulfide was used as the eluting solvent.

RESULTS AND DISCUSSION

This laboratory performed analysis upon 806 fire debris cases in the period of 1984 to 1994. That is an average of 73 cases per year. The yearly totals and

monthly amounts can be found in Table 2. May and August were the busiest months, each with 70 cases submitted over the 8-year period in which monthly statistics were available. In this city, May is the month our schools dismiss for the summer and August is when school reconvenes. The extra fires in these months are juvenile related. The 2 months with the lowest submission totals were January and December which are the cold, wet, and snowy months. The annual number of cases was at a low of 57 in 1987, but showed a rise in the number of cases in each succeeding year until 1992 when it fell to 66.

The breakdown of submissions by agency showed that all agencies, other than the Indianapolis Fire Department (IFD), submitted a rather consistent amount (Table 3). The average for other fire agencies was 27 cases per year. The considerable fluctuation of the IFD submissions may be due to the large size and internal personnel changes. Interestingly, after the 1991 mayoral election with the new mayor taking office in 1992, a new fire chief was appointed. Also a new head of the arson unit was appointed. As pointed out earlier, the total submissions fell in 1992, probably due to the changes in leadership and the uncertainty that accompanies change. This is a fact of life that can cause practical considerations in the allocation of resources for a forensic laboratory.

There were 418 cases in which an accelerant was reported by this laboratory. In 298 of these cases, the accelerant was identified as gasoline. This reflects that approximately 70 percent of the time, when an accelerant is used, it is gasoline. This percentage remained almost constant from 1984 to 1994 (Table 4).

Table 1. Oven Temperature Program Profile

	Initial Temperature	Program Rate	Final Temperature	Hold Time
Initial	40°C	-----	-----	0.50 min
Level 1	40°C	7.5°C/min	65°C	0.75 min
Level 2	65°C	13.0°C/min	135°C	1.00 min
Level 3	135°C	18.0°C/min	280°C	15.00 min

Table 2. Number of Fire Debris Cases Submitted for the 1984 to 1994 Period											
Month	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Jan	4	2	--	--	--	6	14	5	3	2	3
Feb	7	7	--	--	--	7	7	5	2	4	2
Mar	5	9	--	--	--	9	4	9	4	13	2
Apr	8	2	--	--	--	7	2	7	6	9	0
May	7	6	--	--	--	9	8	20	7	6	7
Jun	3	4	--	--	--	4	3	9	11	12	13
Jul	4	1	--	--	--	4	13	4	6	5	8
Aug	5	7	--	--	--	5	17	12	5	10	9
Sep	5	8	--	--	--	3	3	7	3	8	6
Oct	8	12	--	--	--	11	4	7	7	3	5
Nov	7	11	--	--	--	6	7	4	6	9	7
Dec	3	3	--	--	--	3	6	5	6	4	7
Total	66	72	75	57	60	74	88	94	66	85	69

Table 3. Number of Fire Debris Cases Submitted by IFD and All Other Agencies*											
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
IFD	55	50	52	24	35	56	61	67	37	57	30
Other Agencies	11	22	23	33	25	18	27	27	29	28	39

Table 4. Number of Cases with Accelerant Detected												
Year	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**TOTAL**
Number of Cases with Accelerant Reported	24	28	34	29	35	45	52	57	36	40	38	418
Number of Cases Where Gasoline Reported	17	17	24	21	24	35	42	38	28	28	24	298
Percent Gasoline	71	61	71	72	69	78	81	67	78	70	63	71

The Application of Experimental Control Burn Data to the Investigation of Fire Scenes

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The purpose of this experiment was to show how data gathered at control burns can be applied to fire scene investigation. Data was collected on the temperature dynamics of burns, pyrolysis material behavior, and the recovery of ignitable liquids.

MATERIALS/METHODS

Equipment used consisted of thermocouples, video recorders, and structures to burn. Thermocouple wires were set up at several positions between the ceiling and floor including in the accelerant trailer. Information recorded included temperatures, burn times, fuel load, room dimensions, burn patterns, and accelerant types. The fires were allowed to burn freely until visible from the outside. A few minutes were added to allow for normal fire service response time and setup.

RESULTS

In burns under 15 minutes the rooms remained intact, even when an accelerant was used. The floor temperature remained under 300°F in unaccelerated fires, but rose rapidly to 1000°F in accelerated fires. In both accelerated and unaccelerated fires, the ceiling temperature reached 1800° - 2000°F. Rollover was observed when the ceiling temperature reached 1000°F - 1300°F. Complete destruction of the room and surrounding structure was observed in burns which exceeded 30 minutes. The temperatures throughout the room reached 1000°F - 2000°F.

A burn pattern was observed beside a mattress which could be interpreted as an ignitable liquid pattern. However, in this experiment it was caused by melting foam running off the mattress. Another example of a false indicator of an accelerant pour was the presence of a hole in a wooden floor. This was observed in a hallway which was ignited without an accelerant. Holes in wooden flooring can be interpreted as puddling caused by an ignitable liquid (O'Connor 1993). This hole was caused by secondary drop down.

The recovery of liquid accelerant residues from control burns was studied by examining the intensity of the chromatographic pattern recovered and the amount of weathering in the pattern. It was found that longer burn times led to higher temperatures in the area of pour and less liquid residue available for collection. The residues recovered always showed some degree of weathering. During burn times under 15 minutes, the temperatures in the area of pour did not exceed the boiling point range of the liquids typically used as accelerants. In burns exceeding 30 minutes, the temperatures in the entire structure exceeded 1000°F. Since this temperature exceeds the boiling point range of most liquid accelerants, no residue would be recovered unless from a protected area.

CONCLUSION

Experimental control burn data can be invaluable in the investigation of suspect fires.

Observations reported at fire scenes can be compared to the temperature dynamics of control burns to help determine if the suspect fire was accelerated. Pyrolysis material behavior demonstrates the need for caution when interpreting burn patterns. Accelerant recovery studies show when and how liquid accelerant residues should be recovered. This information aids investigators in interpreting liquid accelerant burn patterns of set fires even if ignitable liquids are not recovered.

REFERENCES

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The "Write" Way to Start a Fire

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The use of graphite, commonly found in pencils, has provided a novel method for starting an arson fire without a match or lighter. On July 6, 1994, Desert Vista Hospital, Mesa, AZ, was the victim of arson. During examination of the fire debris, a wooden #2 Berol Ensign 200 yellow pencil was found burned extensively on one side. One piece of pencil graphite was found inside one socket of an electrical outlet that had substantial fire damage. A second piece of graphite was found just below the electrical outlet (Figure 1 and 1A).

Use of this material was found to be a previously undocumented approach to starting a fire. In order to produce a potentially similar device, graphite was removed from a #2 Berol Ensign 200 yellow pencil. The graphite was placed in both sockets of an extension cord lying on a piece of carpet soaked in gasoline. Toilet paper was placed between the graphite. A third piece of graphite was placed across the two pieces from the sockets, creating an electrical short (Figure 2). This particular procedure for starting a fire could easily be overlooked in normal fire investigation. This technique could also be used in conjunction with a controlled power source, such as a switch, breaker, timer, photocell, or motion detector.

This method of fire initiation was employed because of the lack of normal fire starting utensils (matches, cigarette lighter, etc.) at this facility. As a result of this investigation, the suspect confessed to starting numerous fires in Arizona and California using this type of technique.

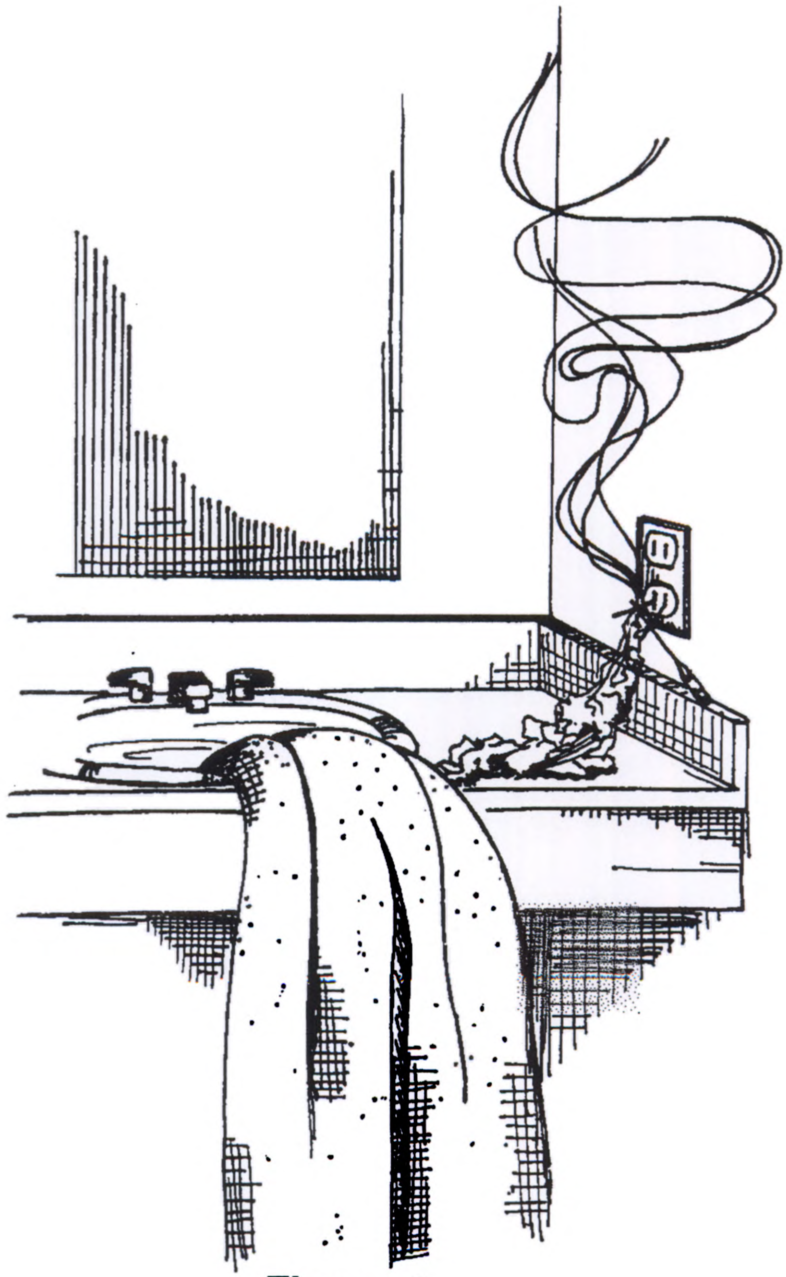

Figure 1

The novel method for starting arson fire of July 6, 1994 at Desert Vista Hospital Mesa, AZ.

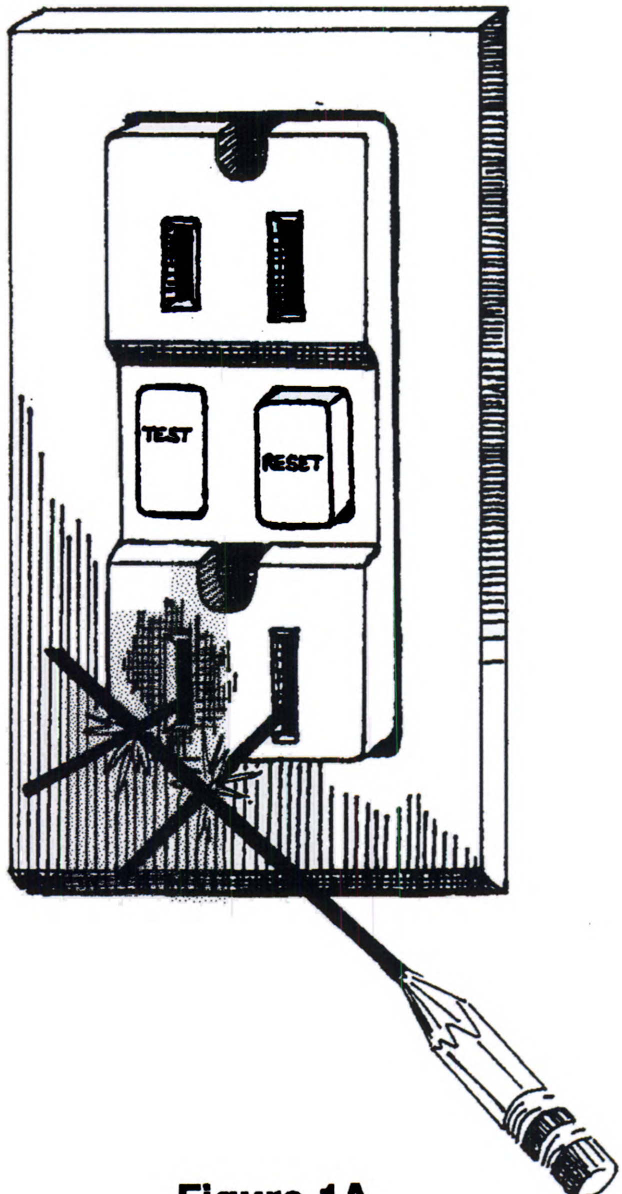

Figure 1A

A close up view of the electrical outlet and graphite device.

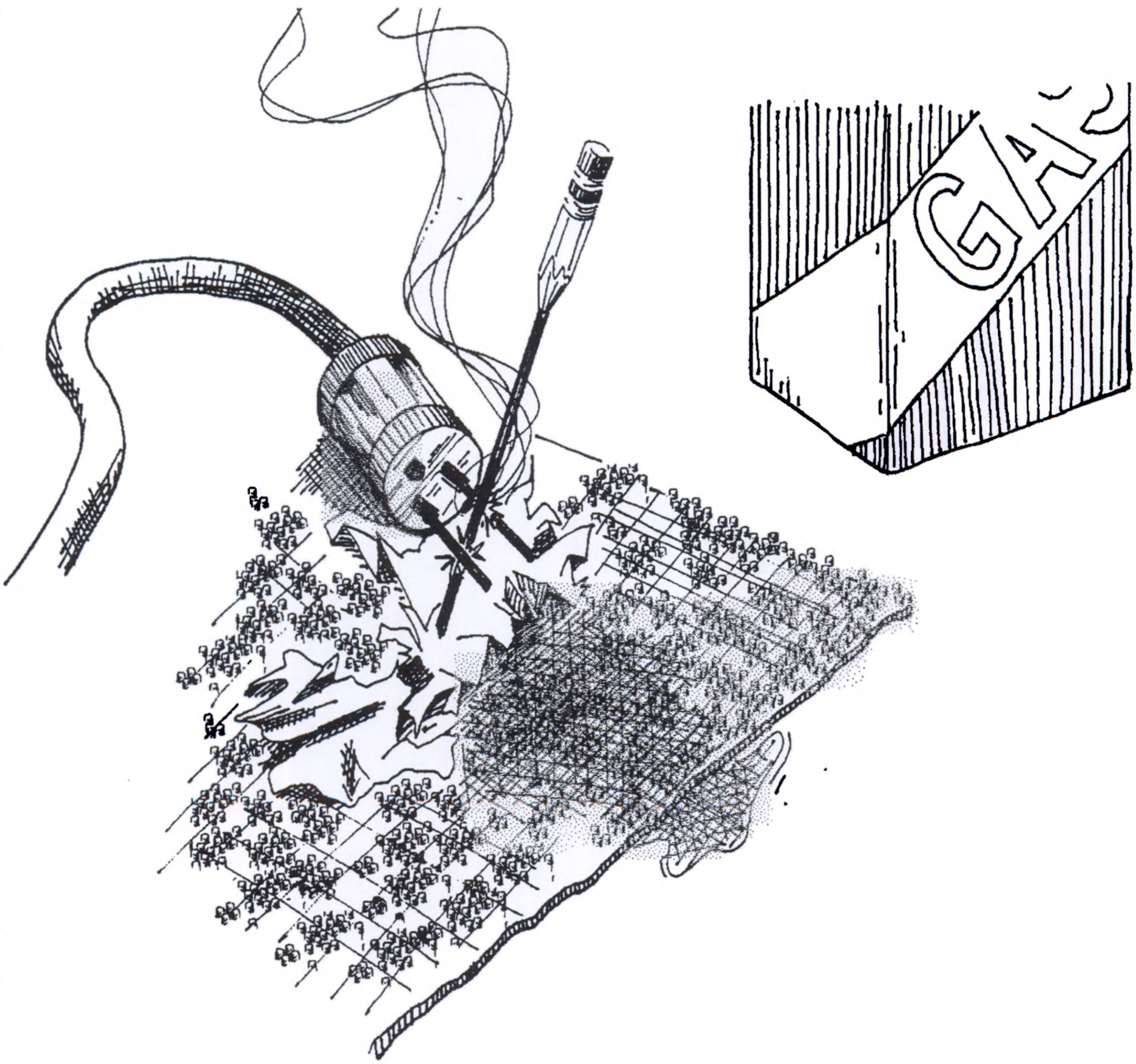

Figure 2

The experimental device used to replicate the hospital fire

Investigation Into Origin and Cause of a Multiple Fatality Fire - Backpackers Hotel, Sydney, Australia

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A fire occurred in the Downunder Backpackers Hotel at Kings Cross at 4:50 a.m. on Sunday, September 17, 1989, resulting in the loss of six lives.

The hotel was being used as accommodation for backpacker tourists. The locality is in an area known for its tourist appeal, frequented by overseas visitors.

The building was three levels and basement, brick and sandstone walls, timber floors, and an iron roof; floors were carpeted. The rear wall was aluminum clad over timber boards. A single stairway provided the only means of access to and from the residential parts of the building. Contained in the entrance lobby were furniture items, including a modular lounge, Coke machine, advertising literature, and an office. A thermal fire alarm system was installed throughout the building.

FIRE

Fire was first observed by security officers, alerted by an alarm bell operating. On opening the front door, they saw flames approximately two feet high on a modular lounge. Within seconds of opening the door, there was a sudden increase in size and intensity of the fire.

All doors to the corridors and the rear patio were open. Hot smoke and gases raced up the stairwell, preventing the escape of occupants from the upper levels. Fire and heat also vented out a laundry door to a rear patio, where it reflected off a brick wall, onto the aluminum clad wall. This wall then melted, exposing the polystyrene filler (insulation) resulting in more smoke and toxic products entering the above rooms.

INVESTIGATION

Prior to commencement of the full investigation, officers from the New South Wales Police Department's Photogrammetry Unit carried out the necessary photography and video work to record the scene. Initial investigations suggested that the fire commenced on or around the modular lounge in the entry foyer.

Carpet from the foyer was taken for further examination for hydrocarbon residue, using microscopical analysis. All tests undertaken proved negative to hydrocarbons.

RECONSTRUCTION

To establish whether the fire could have commenced from a discarded cigarette, both computer modeling and physical tests were carried out.

Many factors were considered in the modeling and analysis was carried out through seven steps. Results of the modeling showed that flashover would have occurred in the fire room after approximately 285 seconds from ignition. After consideration of all

evidence and results from the modeling, the Commonwealth Scientific and Industrial Research Organization advised the Coroner that the fire could have been of the smouldering type, in which case it would take at least 22 minutes to ignite and reach a height of approximately 2 feet.

Tests using lighted cigarettes on a lounge chair proved inconclusive. It was determined from these tests that such occurrence could not be ruled out as a possible cause.

CONCLUSIONS

- It was concluded that no flammable liquid had been used to initiate the fire.
- It was possible for a carelessly discarded cigarette to initiate the fire.
- It was possible that the fire was deliberately lit by means of a lighted match or cigarette lighter, or lighted paper (none of which would leave any trace).

POSTSCRIPT

In September 1992, Mr. Gregory Alan Brown pleaded guilty to lighting this fire, as well as approximately 100 other fires in the Sydney Business District. The initial conclusion (that the fire was deliberately lit by means of a lighted match or cigarette lighter, or lighted paper) of the Coroner proved to be correct.

Examination of Gas-Fueled Central Furnace Reveals Deliberate Alteration of Controls By Arsonist Who Used the Appliance as a Delayed Ignition Device

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Fires that start near furnaces and other heat-producing appliances are generally assumed to be accidental. Some clever arsonists realize, however, that investigators often stop the investigation process prematurely after they conclude the appliances malfunctioned and caused the fires.

The problem is, almost any heat-producing appliance that comes on in response to a thermostat control can be used to cause a fire at a later time. Thus, a fire can occur near an appliance that is known to cause fires hours after occupants leave a structure. It can be a perfect setting for an arson fire.

In one case, a gas-fueled central furnace was used to start a fire many hours after people left the home. The arsonist did not place combustibles or liquid accelerants around the furnace, ignite them, and leave. Rather, he started it by causing the furnace itself to overheat.

In a central furnace, the fan moves air through the heat exchanger to prevent overheating. As long as sufficient air moves through the furnace, heat is drawn off and distributed throughout the home. When the fan fails, the temperature inside the furnace rises rapidly, and if there is no intervention to shut down the burner, the exterior surfaces of the appliance can become much hotter, possibly causing ignition of nearby combustibles.

To prevent this situation, industry standards compel manufacturers to install a high-limit switch that quickly shuts down the main burner when the temperature reaches a certain level. The high limit opens, which interrupts electrical power to the main burner, and the system shuts down safely.

If the furnace is to overheat, two failures must occur. The fan must cease first functioning, and then the high limit switch must fail to shut down the system. If only one, but not both, failures occur, the furnace will not overheat.

For many arsonists, it is easy to manipulate a fan failure. One way is to just wedge an object into the fan and hope a locked rotor in the blower motor does not overheat, short, and trip a fuse or breaker supplying power to the furnace. If that happens, the effort is in vain, because the entire furnace shuts down when electricity stops supplying the power.

A more certain approach is to cut the fan belt, which allows the motor to run, but prevents the fan from moving air. The easiest method, though, (the

choice used in this case) is to cut the wires running to the blower. With those conductors cut, the blower is never energized and air does not move through the furnace.

Next, the arsonist must do something about the high-limit switch. The challenge is more difficult because it is essential that electrical power be maintained rather than interrupted, as with the fan.

It can be accomplished, however, by simply switching terminal points on the combination fan/limit switch. This bypasses the high-limit switch and maintains power to the burner, regardless of how hot the furnace gets. Since the new terminal point connection is located near the old one, it is unlikely that an investigator who is only vaguely familiar with furnace wiring will ever note the deception.

The two modifications—disabling the fan and bypassing the high-limit switch—assure that a furnace will overheat. Ignition is inevitable if combustibles are very close to the furnace.

But one last challenge awaits the arsonist—timing the event. The solution to that problem is usually mounted on a living room wall. The thermostat can help achieve delayed ignition.

Because the thermostat determines when a furnace comes on, all the arsonist must do is simply turn down the thermostat so that it will come on later. In this case, since the outdoor temperature is colder than inside, it was only a matter of time until the indoor temperature dropped to the thermostat's new setting.

When the furnace kicked on many hours later, the arsonist was several states away and had created what appeared to be an air-tight alibi.

This type of arson can easily be missed and classified as accidental. It demands a careful examination and possibly even radiological examination of the high-limit control combined with a microscopic examination of the severed fan conductors to show that a fire like this was set deliberately.

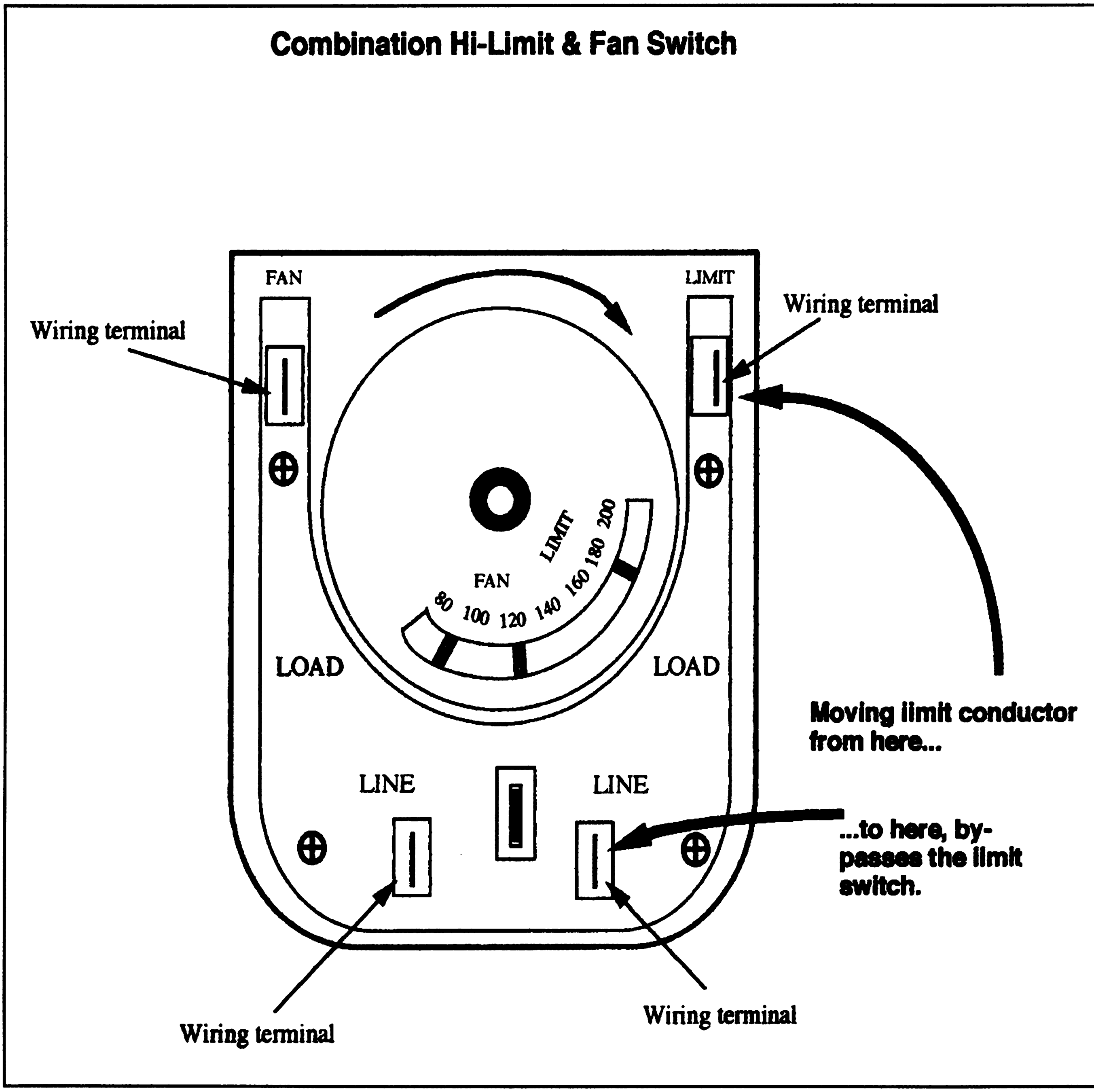
Combination Hi-Limit & Fan Switch
FAN
LIMIT
Wiring terminal
Wiring terminal
LIMIT
200
180
160
140
120
100
80
FAN
LOAD
LOAD
Moving limit conductor from here...
LINE
LINE
...to here, by-passes the limit switch.
Wiring terminal
Wiring terminal

Figure 1.

Proper Fire Scene Examination, Reconstruction, and Evidence Collection Lead to Expert Electrical Fire Analysis and Analytical Interpretation in Fatal Fire

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A house fire left one person dead and one badly injured. A thorough fire scene examination, conducted by several agencies, led to the correct origin and cause determination of the fire as an electrical malfunction and the action to ban or re-engineer the failed electrical product, so that similar fires may be avoided in the future.

The scene was examined in accordance with protocol established by the National Fire Protection Association (NFPA) 907M, Determination of Electrical Fire Causes and, later in NFPA 921, Fire and Explosion Investigations. The area of origin was determined through the examination of burn patterns and witness interviews. the only possible ignition sources in the area were electrical components. Proper documentation, handling, and collection of the evidence preserved the items so that experts could give technical assistance and provide analytical explanation of the fire cause.

An electrical wall outlet, an extension cord, a lamp cord, and a floor lamp were examined. The two-prong attachment and end cap on the lamp cord was a clip-on replacement type that was sold in stores nationwide. After eliminating other components, the male end of the lamp cord attachment cap and the female end of the extension cord receptacle were dissected.

The examination found that both prongs of the male end contained evidence of severe arcing and melting, plus there was pitting and arcing where the clip-on cap's teeth had pierced the cord's insulation and had been in contact with the copper conductor. There was a black pyrolyzed area visible on the components.

It was determined that the cause of the fire was due to the poor connection made by the clip-on teeth of the replacement cap, which caused increased resistance heating and further breakdown of the connection and the interior of the cap. Finally, arcing occurred which ignited dust or the skirt below the couch where the cords had been placed.

The manufacturer of the cap brought several experts to fight this determination. Each had a chance to find another cause, but failed. As investigators, we can learn from the outcome of this case. By

conducting a thorough scene examination, using all available resources, preserving the integrity of the evidence, and recognizing our limitations in order to call in outside experts for assistance, the investigators were able to define the exact origin and cause of the fire. Steps have been taken to have these caps banned or re-engineered so that this tragedy will not be repeated.

An Arson to Cover Up an Arson?

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On December 2, 1991, a fire swept through a frame residence in Mt. Pleasant, New York, killing a 11 1/2-week-old infant who at the time was under the care of an au pair. Standard arson investigation techniques determined that there were three separate fires and that they were suspicious in origin. The au pair was detained and despite intense questioning, a confession was not obtained. However, detectives did notice that the au pair's eyelashes were singed. This and her statement that no other person could have entered the house without her hearing them pointed to her as the only possible suspect. She was subsequently arrested. The case quickly gained national media attention. Samples of fire debris from the fire scene including a box of matches, the infant's clothes and diaper, a one-liter soda bottle with suspicious liquid, and a portion of the au pair's bedspread were analyzed by both the Westchester County Forensic Laboratory and a defense laboratory. The defense counsels, investigators, and then the Westchester County Forensic Laboratory examined the crime scene.

The au pair was indicted by a grand jury and in May 1992, the trial commenced. During the trial, the defense counsel raised various issues of shoddy general crime scene technique by the investigating agencies such as entry point determination, position of bloodstains, glass breakage, and evidence collection and documentation. After a month-long trial, the au pair was acquitted.

Our reconstruction of the evidence indicated that the au pair first set fires in the lower-floor bedrooms, perhaps with the intention of "rescuing" the baby from the nursery. However, the baby was overcome by combustion byproducts as indicated by a substantial level of carbon monoxide in the infant and the au pair then set fire to the baby and the nursery to cover up the first fire. The presentation will cover the various articles of evidence that were obtained, their examination, the results obtained, their relevance to the case, and the experiments that were done in the laboratory to try to obtain more information. It will also examine a discrepancy between the results of the accelerant testing from the Westchester County Forensic Laboratory and the defense laboratory of an item from the au pair's room. Items that could have shed more light on the case, but were not obtained will also be addressed. This case demonstrates the need for a more comprehensive interdisciplinary approach to arson crime scene searches and coordination of investigators with laboratory personnel.

Impact of Microprocessors on the Interpretation of Fire Accelerant Chromatograms

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Forensic scientists required to identify remains of accelerants in fire debris are faced with a serious challenge of interpreting chromatographic data. Improvements in microprocessors and software have provided forensic scientists with new means to help interpret chromatograms of complex residues in fire debris. This paper emphasizes understanding the factors responsible for forming complex chemical residues in fire debris and how to incorporate these factors in establishing a comprehensive library of standards of known accelerants, substrates found in fire debris, and combinations of accelerants and substrates.

To understand the formation of complex chemical residues, it is necessary to gain an insight into the accelerant behavior in fire. Complex hydrocarbons/petroleum products are inherent in many household furnishings, building materials, household chemicals (such as floor wax and carpet cleaners), or as a result of spills or tracks. Applied accelerants may soak vertically into the surface, splash and become trapped behind baseboards, or spread horizontally under furniture. Eventually, these accelerants will dissolve or mix with the existing hydrocarbons to form an "accelerant cocktail." If conditions are favorable, the accelerant vapors will ignite. Depending on environmental conditions, the accelerant cocktail partially or totally oxidizes under the effect of open flames. As furniture and other materials in the vicinity of the fire reach their ignition temperatures, they begin to burn producing pyrolytic products. With rising temperatures, some of the more volatile components of the trapped accelerant cocktail are lost by evaporation. Incomplete oxidation produces free carbon particles or soot which may adsorb the vaporized mixture of accelerant cocktail and pyrolytic products to become a source of contamination. Applying water to extinguish the fire may cause partial dissolving or physical removal of the accelerant cocktail and pyrolytic product residues. Further loss, contamination, or altering of the accelerant composition may occur at the time of sample collection, storage, or transportation.

Understanding the accelerant behavior in fire provides the knowledge needed to build and continuously update a chromatographic standards library of accelerants and materials contacted before, during, and after the fire. Because it is possible to acquire and store massive amounts of data on today's computers, a large library of all accelerant/substrate combinations can be built. Chromatography software packages facilitate comparing small fragments of patterns that would have been impossible without graphical enhancements and manipulation capabilities. Most of the available software will allow the forensic scientists to select the desired pattern fraction from an unknown and enhance its pattern without changes to the raw data. Once that fraction is displayed on the monitor, a chromatographic pattern of one or many standards can be overlaid to determine if similarities exist. Obviously, the larger the standards library, the more accurate the comparison will be. An example of a library containing one accelerant poured on carpet which is laid on carpet padding glued by an adhesive to plywood floor is described in Table 1.

The study shows that use of fast computers, large capacity storage media, and compatible software have a remarkable impact on improving graphic

manipulation without compromising the integrity of raw data. Graphic manipulation provides the analyst with vastly superior versatility to perform peak matching of an unknown to known standards over that of manually superimposing hard copy chromatograms. The combination of the experienced eye of the interpreter; multiple graphic functions (such as scale adjustments, overlaying, and subtraction of one chromatogram from another); and fast microprocessors can produce accurate and prompt identification of fire accelerant chromatograms.

No.	Variable	Accelerant / substrate description
1	α	Pure accelerant
2	α 1	10% evaporated accelerant
3	α 2	20% evaporated accelerant
4	α 3	30% evaporated accelerant
5	α 4	40% evaporated accelerant
6	α 5	50% evaporated accelerant
7	α 6	60% evaporated accelerant
8	α 7	70% evaporated accelerant
9	α 8	80% evaporated accelerant
10	α 9	90 % evaporated accelerant
11	β	Unburnt carpet
12	γ	Unburnt padding
13	δ	Unburnt adhesive
14	λ	Unburnt wood flooring
15	β α	Unburnt carpet and accelerant
16	βγλ α	Unburnt carpet, padding, wood flooring; and accelerant
17	βγδλ α	Unburnt carpet, padding, adhesive, wood flooring; and accelerant
18	β B	Burnt carpet
19	γ B	Burnt padding
20	δ B	Burnt adhesive
21	λ B	Burnt wood flooring
22	βB α	Burnt carpet, then add accelerant
23	βBγBδBλB α	Burnt carpet, padding, adhesive, wood flooring; then add accelerant
24	αBβBγBδBλB	Accelerant burnt with carpet , padding, adhesive, wood flooring

Table 1. Suggested standards library entries for one type of each - accelerant, carpet, padding, adhesive, and flooring.

Computer-Assisted Data Reduction for Arson Analysis of Samples Utilizing an Ion Trap Gas Chromatograph/ Mass Spectrometer

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A chemist often encounters chromatograms that are very difficult to interpret during the analysis of samples for the presence of a flammable liquid. Utilizing a gas chromatograph/mass spectrometer (GC/MS) may often help identify flammable liquids by searching for specific ions that may be attributed to the presence of certain classes of compounds. Extracting ions from a total ion chromatogram is tedious and may take up to 30 minutes per sample. A keystroke sequence program (MACRO) has been developed that allows the controlling computer to extract the desired ions and save the data to a print spooler while the gas chromatograph (GC) is recycling for the next sample.

A Perkin-Elmer Ion Trap Mass Spectrometer (MS) with automatic gain control connected to a Perkin-Elmer Auto System GC was used. The GC analytical column was a Supelco SPB™ -5, 15 m, 0.25 mm ID, 0.25 um film thickness, programmed from 60°C - 250°C at 10° per minute with a 1 minute hold at 60°. The injection port and transfer line were held at 250°C. A split ratio of approximately 1:40 was utilized. The MS was set for full scan from 50 to 400 AMU with a 20-minute run time and a 120-second filament delay time. Tuning the MS was accomplished using the standard tune program. Column resolution was checked by using the Column Resolution Test Mix (Restek Corp. Cat. #31224) to assure proper performance. Samples were extracted following the ASTM Designation E-1412-91, Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residue From Fire Debris Samples by Passive Headspace Concentration. Retention times were indexed by using a hydrocarbon mixture, C7 - C19 (Hewlett-Packard Part #8500-4705). Commercial reference standards were purchased from local retail merchants.

Ions selected for computer extraction were 57, 71, and 85 (indicative of paraffins); 83, 97, and 111 (indicative of monocycloparaffins); 91, 92, 105, 106, 199, and 120 (indicative of alkylbenzenes); 128, 142, and 156 (indicative of naphthalenes); 58, 93, and 136 (indicative of turpenes); and 105 and 106 (indicative of xylenes). In reviewing the printouts of the following chromatograms, a charcoal starter is compared with an unknown. One may observe that each ion scan is actually a separate chromatogram. Although relative intensities may vary according to concentration, retention time correlation is excellent for paraffins, monocycloparaffins, alkylbenzenes, turpenes, and xylenes.

The advantages of using extracted ion chromatograms are that instead of only one chromatogram, an analyst may evaluate many chromatograms obtained from one GC/MS data set. Even the lack of ions may be of significance, as is evident in examination of the accompanying extracted ion chromatograms for naphthalene ions. A chemist may rapidly expand an analysis by obtaining the mass spectrum of individual compounds as determined by extracted ion comparisons. The use of a MACRO standardizes and greatly enhances the power of GC/MS procedures.

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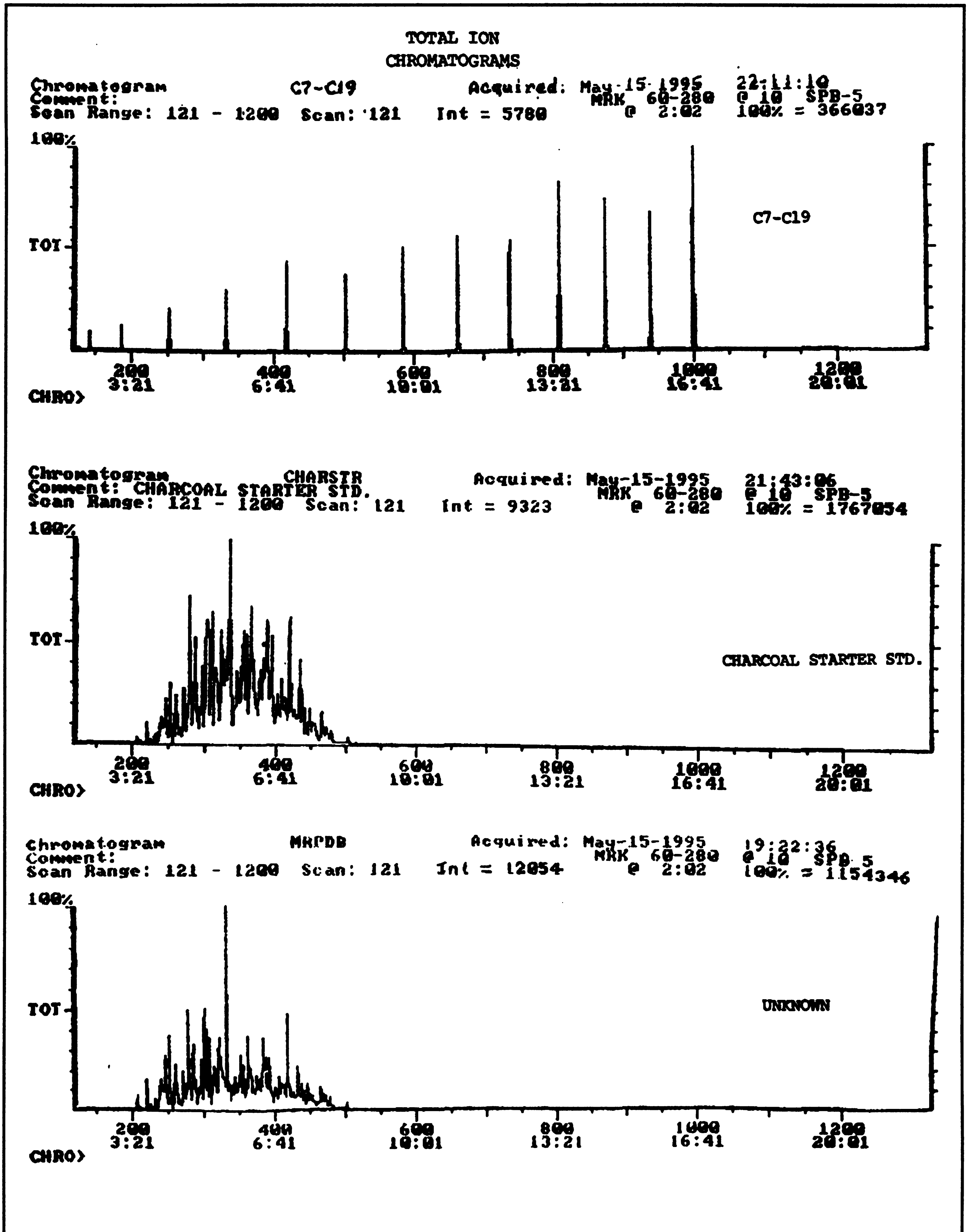

Figure 1. Total ion chromatograms of C7 - C19, charcoal starter and an unknown.

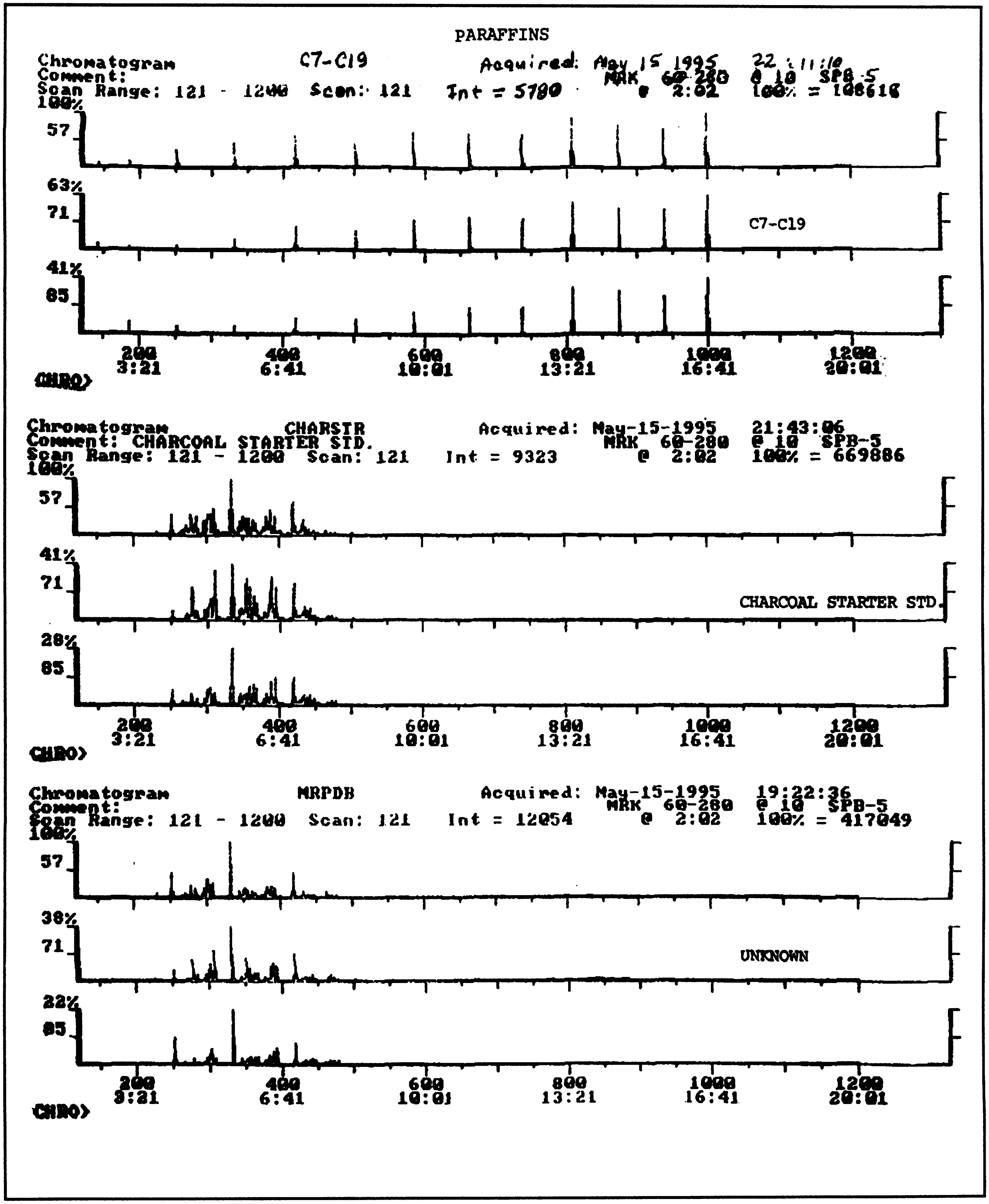

Figure 2. Paraffin extracted ions of C7 - C19, charcoal starter and an unknown.

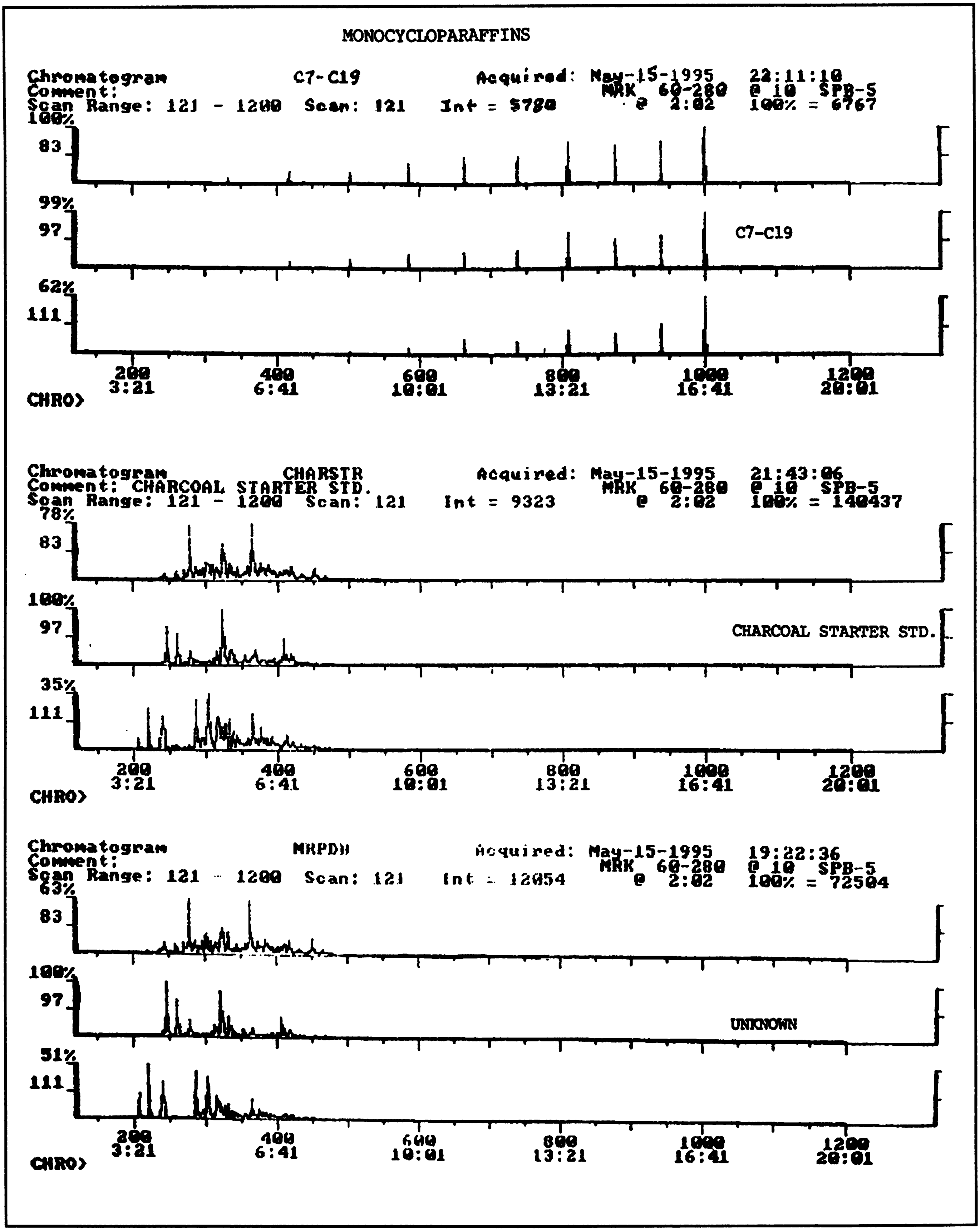

Figure 3. Monocycloparaffins of C7 - C19, charcoal starter and an unknown.

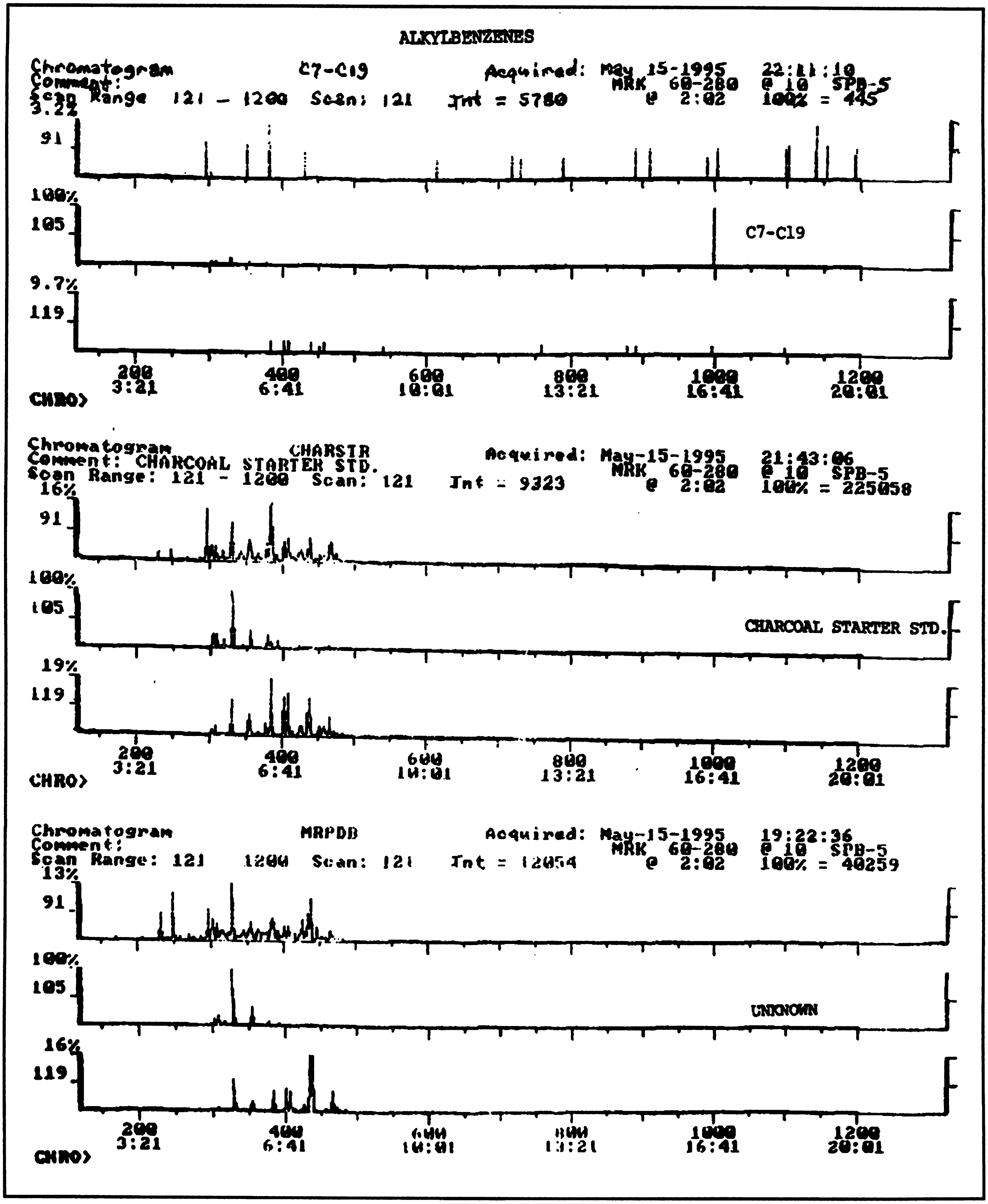

Figure 4. Alkylbenzenes of C7 - C19, charcoal starter and an unknown.

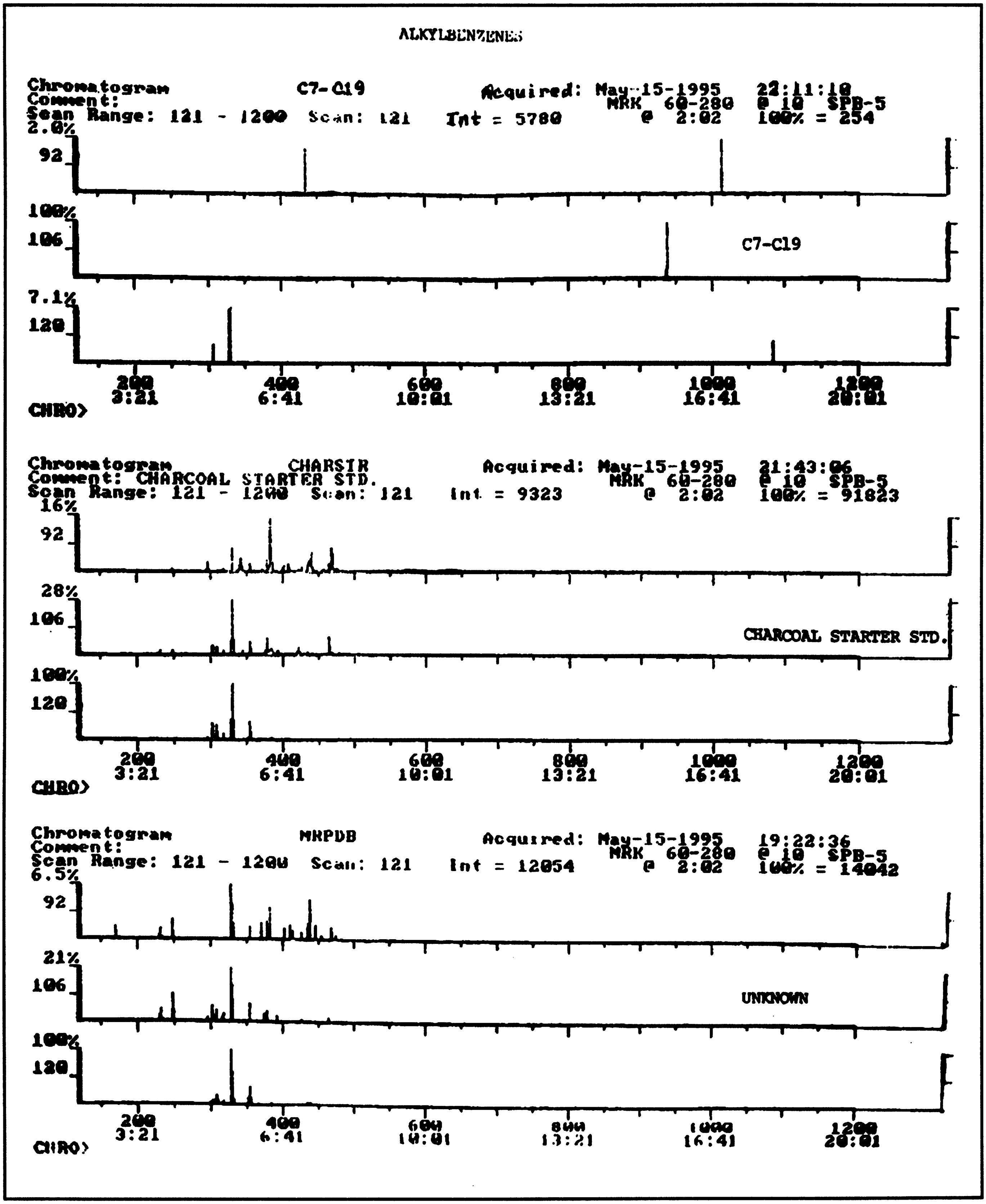

Figure 5. Alkylbenzenes of C7 - C19, charcoal starter and an unknown.

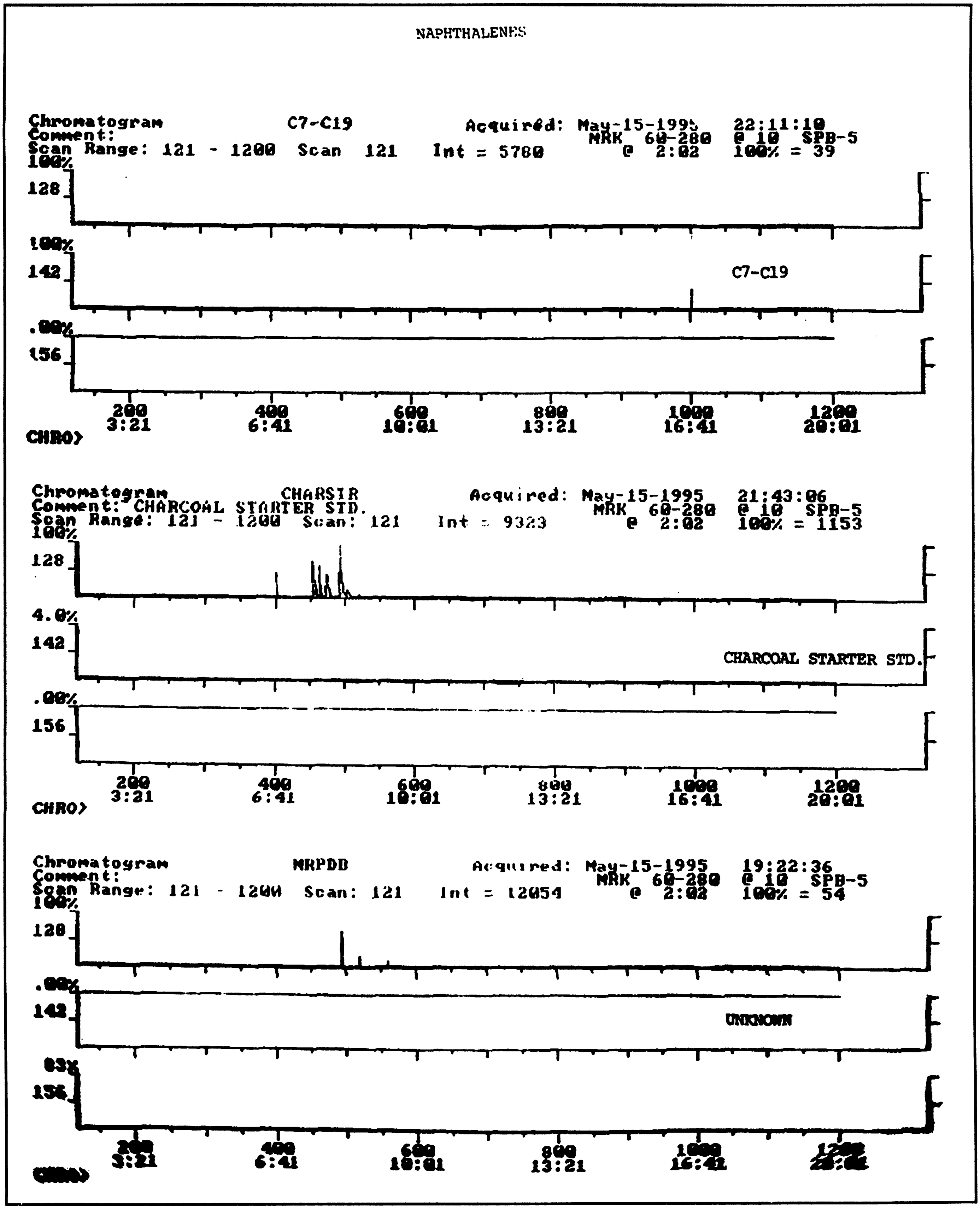

Figure 6. Naphthalenes of C7 - C19, charcoal starter and an unknown.

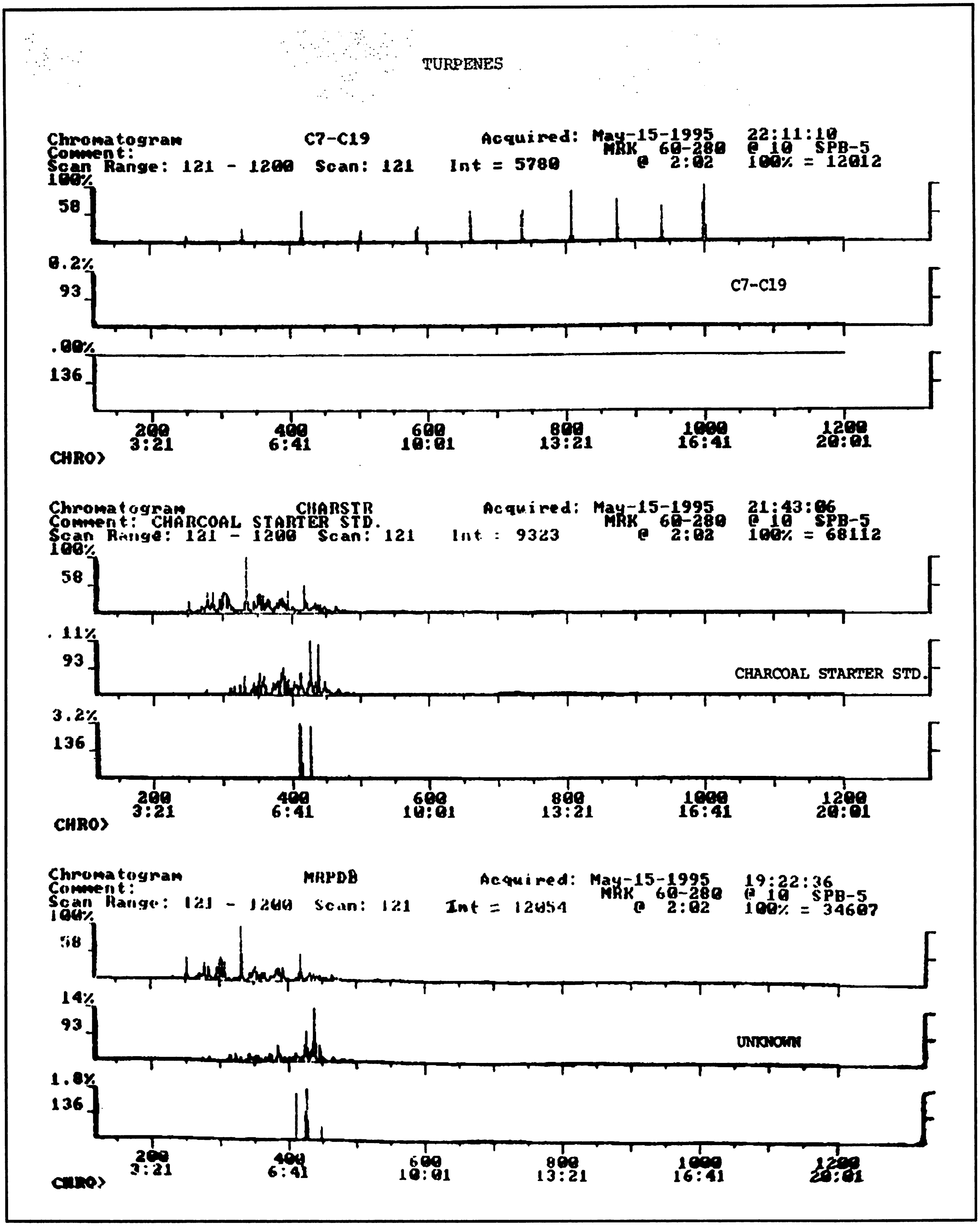

Figure 7. Turpenes of C7 - C19, charcoal starter and an unknown.

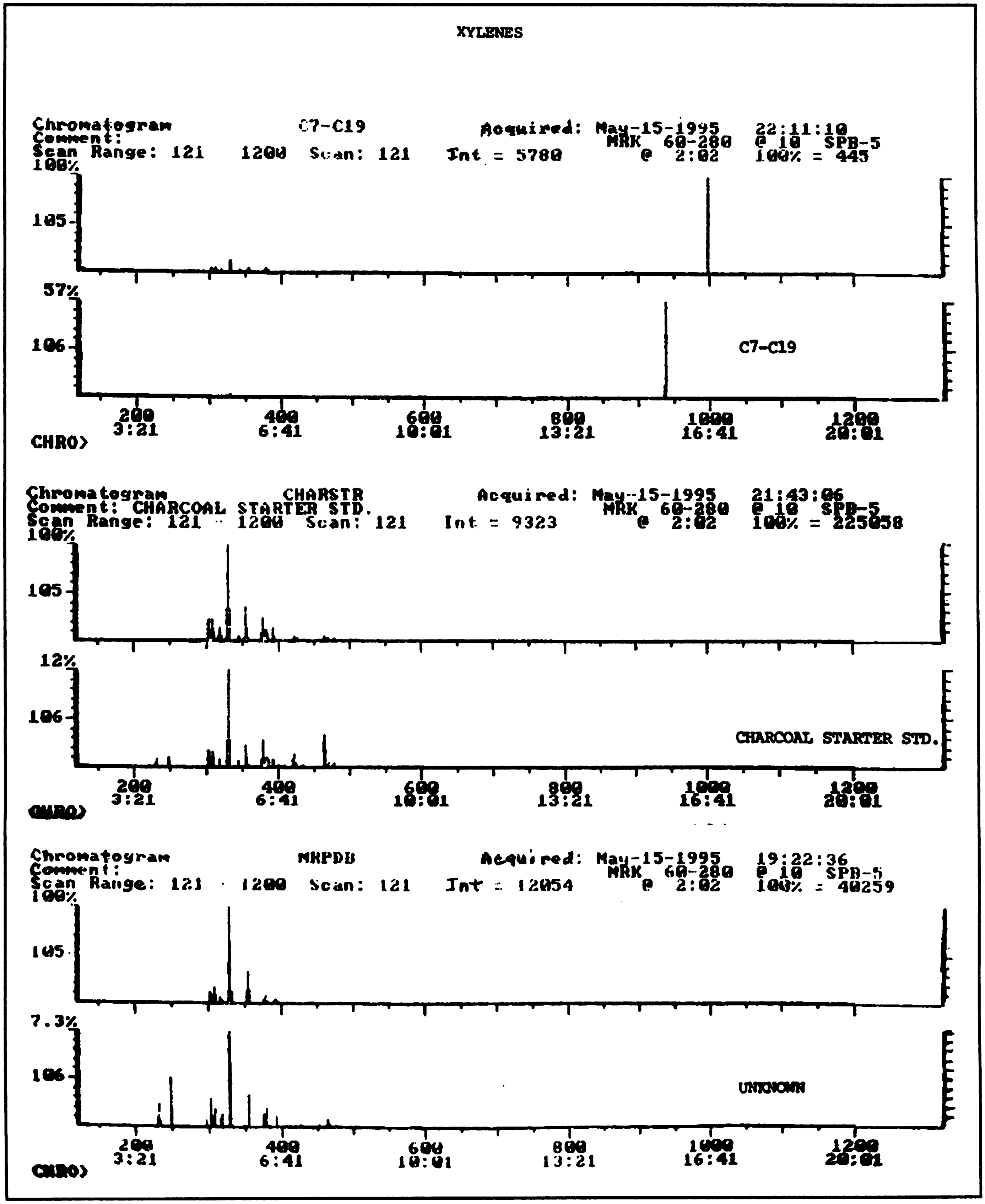

Figure 8. Xylenes of C7 - C19, charcoal starter and an unknown.

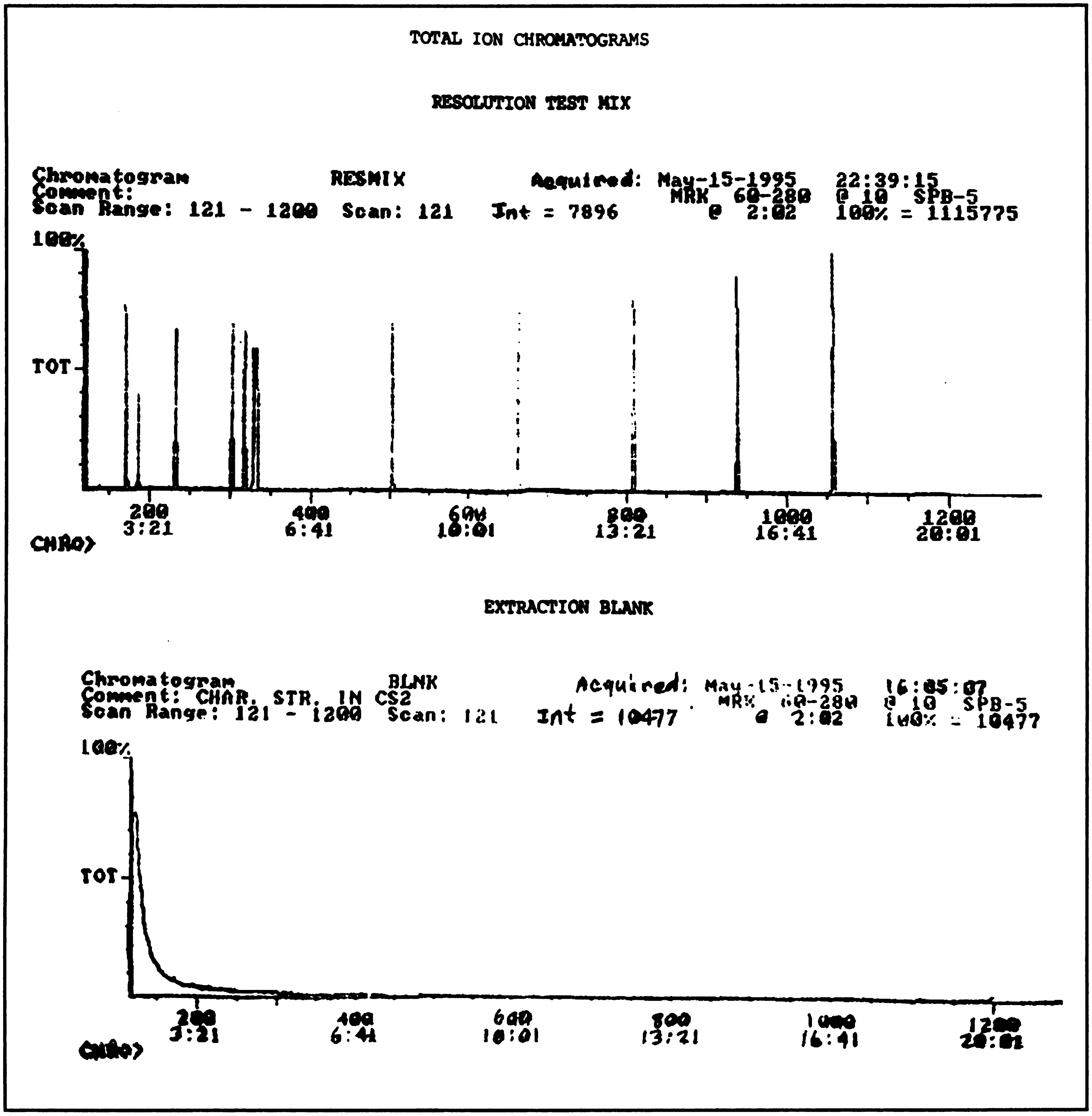

Figure 9. Total ion chromatograms of resolution test mix and the extraction blank.

The Use of the Internet to Locate Information Useful in Fire Investigation

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The Internet is a worldwide network of computers linked transparently. Use of the Internet has increased dramatically over the last few years. From it's beginning in the late 1960's with two users to the current two million users, the Internet connects the world. Users include people from all parts of the world and of all ages. This connectivitity allows people to discuss various topics from flower arranging to methods of setting fires and making destructive devices.

The Internet can be easily accessed with a computer, modem, and a phone line. There are several companies that sell Internet services. Internet access is also provided by local universities, libraries, and government agencies.

There are several features available on the Internet. These features include: E-mail, gopher, File Transfer Protocol (FTP), and newsgroups. E-mail is a method of communication that has become very popular in the last few years. E-mail allows people to send and receive messages and files all over the world. Gopher is a search tool that allows users to search the Internet by using keywords. This allows a rapid search of large databases around the world. FTP is a feature that allows a user to log into a remote computer and download information to their computer. Newsgroups are really worldwide discussion forums. These groups are created by people with common interests and are open to anyone with newsgroup access. These groups number in the thousands and are generally not moderated, meaning any message sent to the group will be posted. Newsgroups are a common source for information of clandestine activities. An example of information found in a newsgroup is:

> Subject: Re: NAPALM
> From:
> Date: 26 Apr 1995 16:57:19 -0500
> Message-ID:
>
> L L@prodigy.com wrote:
> > WHAT IS THE EASIEST WAY TO MAKE NAPALM?
>
> This is probably a stupid thing to broadcast, but there is a readily available commercial version of a napalm-like substance on the market already. Go to your local office supply store and buy, if you haven't figured it out already—Rubber Cement. Note: It is extremely flammable; do not use near fire or flame.

The use of the Internet can be a valuable tool for the fire investigator and the forensic scientist. The time required to learn the use of the Internet is minimal compared to the time devoted to the completion of a complex investigation or analysis. In the last few months the use of graphical user interfaces to the Internet have allowed for all the features discussed along with the viewing of digital images. This new access reduces the time required to learn how to navigate the Internet.

Quality Assurance and Clean Metal Paint Cans

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Clean metal paint cans have been recommended for the collection and preservation of fire debris samples (DeHaan 1991). The durability and impervious nature of metal paint cans have made them the container of choice in Suffolk County.

One function of the quality assurance program developed at the Suffolk County Crime Laboratory is to assure the quality of the cans used for the collection of fire debris. To this end, the laboratory tests individual deliveries and packages of new metal paint cans before they are used for the collection of fire debris samples. This testing has included cans intended for use by both the laboratory and the Suffolk County Arson Squad.

In the past, we have found that the background obtained from cans was minimal and unlikely to interfere with interpretation. However, we have recently detected significant background contaminants that could interfere with the analysis of fire debris samples.

MATERIALS AND METHODS

New uncoated quart and gallon paint cans were obtained through a local distributor. Cans were received packaged in brown paper wrap as shipped by the manufacturer. A can of each type and from each package was selected at random. The procedure used to analyze each can was that employed by the laboratory to concentrate flammable and combustible liquid residues from fire debris samples. All cans tested were subjected to a passive headspace concentration technique followed by analysis with a gas chromatograph equipped with a mass selective detector.

A short length of string was tied to a paper clip. Then a 1.5 cm segment was cut from an activated charcoal strip (Pro-Tek® Systems, Inc., Cromwell, CT). The strip and paper clip were suspended in the can by allowing a portion of the string to protrude from the can and then closing the lid tightly over the string. Each can was incubated in an 80°C oven for a minimum of 3 hours. The charcoal strips were eluted with 100 µL to 2002 µL of carbon disulfide and 2 µL aliquots of the carbon disulfide extracts were injected into the gas chromatograph.

A Hewlett-Packard (HP) 5890 Gas Chromatograph equipped with a HP 5970 Mass Selective Detector and a HP 59940A Mass Spectrometry Chemstation was used for the analyses. Chromatography was performed with an HP Ultra 1 Column (25-m by 0.2-mm, 0.33-µm film thickness) with helium as the carrier gas at a rate of 1 mL/min. The gas chromatograph was operated in split mode with a split ratio of 20:1 and temperature programmed with an initial temperature of 35°C (held for 2 minutes), 12°C/min to 155°C (zero hold), 23°C/min to a final temperature of 275°C (held for 10 minutes). Injector and detector were at 290°C.

RESULTS AND DISCUSSION

The source of the background has been traced to the manufacturing process. The type and degree of contamination has been found to differ between shipments and manufacturer. Examples of the types of background contamination detected include the aromatic series from toluene through 1,2,4-trimethylbenzene (Figure 1) and normal alkane distributions from C15 through C24 exhibiting classic characteristics of a distillate product (Figure 2, Top). In addition, Figure 2 (Bottom) shows the results obtained when kerosene was added to a gallon can exhibiting the normal alkane background contamination. These results demonstrate the importance of a comprehensive quality assurance program.

The presence of any background contaminant that may complicate interpretation is not desirable. The laboratory has been able to eliminate or reduce background contamination by heating the cans and lids in an oven. We have found that cans from different packages or manufacturers cannot be treated equally. Therefore, the methods have ranged from oven heating at 180°C for 30 minutes to heating at 100°C under vacuum for 1 hour.

As a result of the above findings, the following policy was implemented. All new metal paint cans purchased for use by the Arson Squad are shipped directly to the laboratory for storage. The cans are distributed to the Arson Squad only after individual packages of cans have been analyzed and certified for use. The cans are assigned a unique laboratory lot number. Each can is individually marked with the respective lot number to permit their identification upon return to the laboratory.

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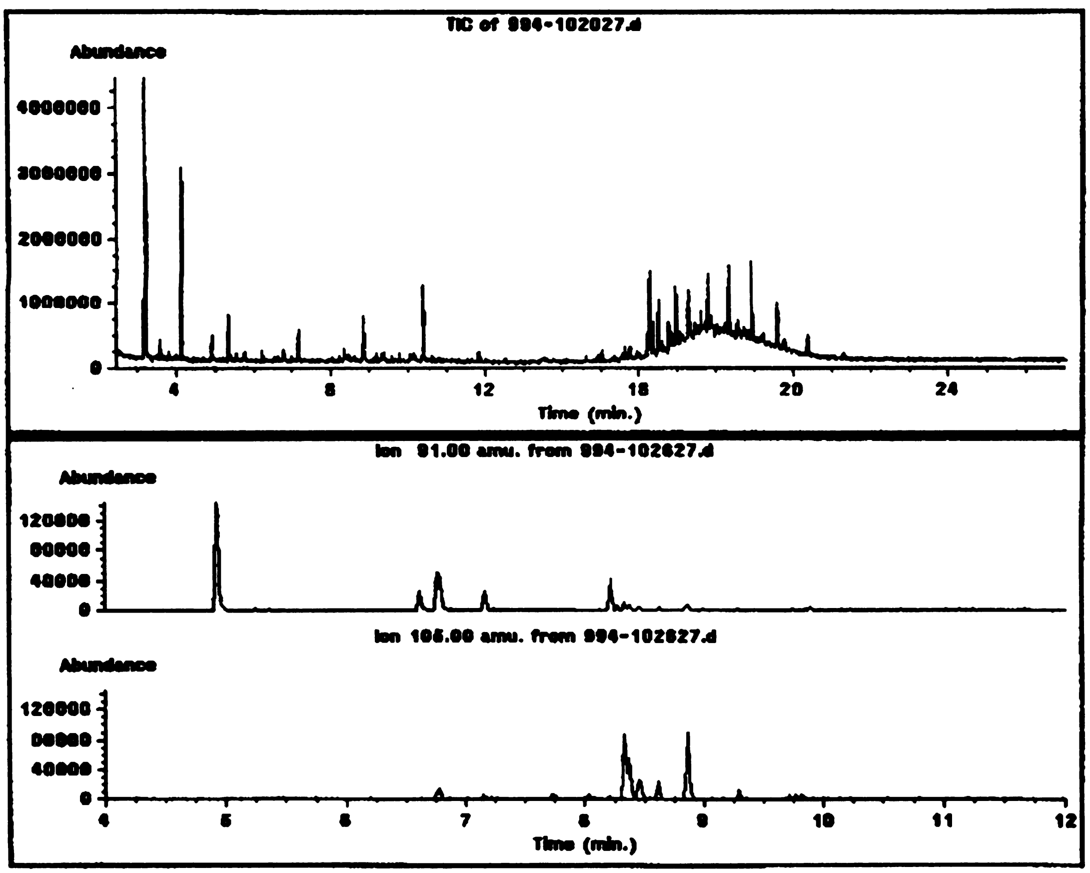

Figure 1. Total ion and extracted ion chromatograms, results of passive headspace concentration of a clean one-gallon metal paint can.

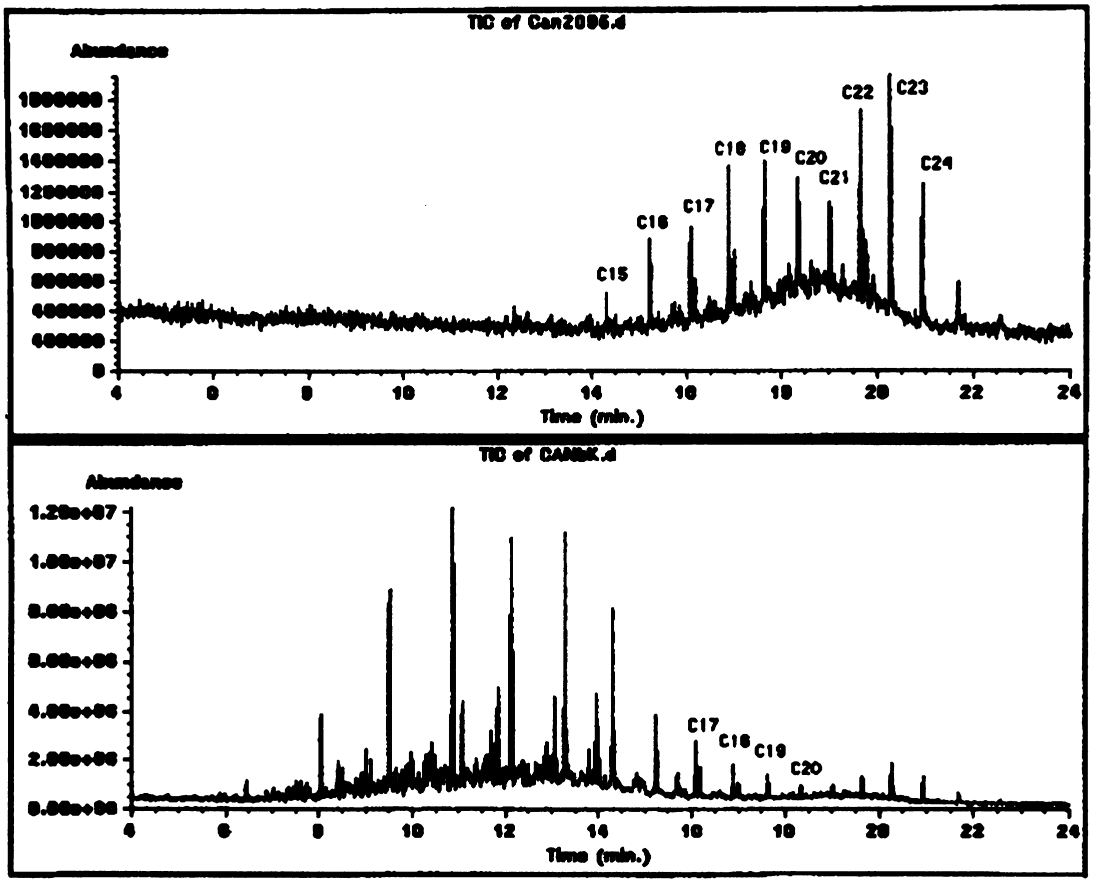

Figure 2. Top: Total ion chromatogram, results of passive headspace concentration of a clean one-gallon metal paint can. Bottom: Total ion chromatogram, results of passive headspace concentration of a one-gallon metal paint can (from the same package as the can above) containing 0.05 μL of neat kerosene.

Chromatographic Data Interpretation in Accelerant Analysis

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The purpose of this work was to develop and evaluate a data presentation method to facilitate interpretation of chromatographic data acquired in accelerant analysis.

Since the early 1980's the University of Tennessee Toxicology Laboratory has employed an injection standard consisting of a series of components expected to be present in petroleum-based accelerants, many of which are quite refractory in that they survive the conditions of the fire and can be recovered from debris (Stafford 1987). The original injection standard has been modified to include all the markers in ASTM Standard E-1387-90. Table 1 is a list of the markers listed in order of increasing retention time on a methylsilicone column. In practice two standards are used. One consisting of those components from toluene through n-tetradecane is run prior to each series of debris extracts chromatographed. This covers the range components expected in class 2 (gasoline) and class 3 (charcoal lighter fluids, etc.) accelerants and serves for the majority of cases encountered. If the chromatogram of an extract indicates the possibility of a class 4 (kerosene) or heavier accelerant, then a standard consisting of toluene through n-tricosane is run immediately after completion of chromatography of the case extracts. A running tabulation of the retention time and magnitude of each component of the standards is maintained to monitor system performance.

After the chromatogram of an extract has been acquired, the magnitude (peak area) of peaks eluting at retention times corresponding to those of the standard markers is extracted, tabulated, and converted to a relative frequency table with the most abundant peak assigned a value of 100, and each of the other peak abundances assigned a value as a percentage of the most abundant peak. Table 2 is an example of data from the chromatography of the extract recovered from known raw gasoline. This procedure is exactly analogous to the data treatment often employed with mass spectral information, and of course it can be plotted and presented as a relative frequency diagram.

There are several primary advantages to this type of data treatment. By using the relative frequencies at the marker retention times the chromatogram may be simplified in that contributions of many pyrolysis products do not interfere. Also, if a known accelerant is selectively evaporated and the chromatograms of the residues at various stages of evaporation are acquired and the data plotted, it is possible to obtain a series of graphs which will aid in assessing the degree of weathering in case samples. This series may also be useful in demonstrating (for example, in court or in teaching) how accelerant composition changes with exposure. Another feature of this data treatment is that it may be used in detecting residues from accelerant mixtures. For example, if a mixture of gasoline and kerosene were used, the plot would show a bimodal distribution which may not have been quite as evident in the presence of interfering components. Treating the data from the front and back ends of the chromatogram independently may elucidate the composition of the mixture quite nicely.

While the described mechanism is useful, it should not be used as the sole criterion for evaluation;

but used with everything else that is known, and a good measure of common sense and objectivity. One caveat: if a pyrolysis component coelutes with one of the markers it can skew the data and will have to be detected and dealt with appropriately.

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Stafford, D. T. Fire scene investigation, Part 2: Laboratory analysis. *Crime Laboratory Digest* (1987) 14(1):7-17.

Table 1. Injection Standard

Toluene	Naphthalene
n-C8	n-C12
Ethylbenzene	2-Methylnaphthalene
p-Xylene	n-C13
m-Xylene	n-C14
o-Xylene	n-C15
n-C9	n-C16
n-Propylbenzene	n-C17
3-Ethyltoluene	Pristane
4-Ethyltoluene	n-C18
1,3,5-Trimethlbenzene	Phytane
2-Ethyltoluene	n-C19
1,2,4-Trimethylbenzene	n-C20
n-C10	n-C21
Indan	n-C22
n-C11	n-C23

Table 2. Relative Frequency Data Tabulation Raw Gasoline			
Marker	Retention Time/Min.	Area	Relative Area Percent
Toluene	4.14	9.409	100.00
n-C8	5.12	0.767	8.15
Ethylbenzene	6.17	2.207	23.45
p,m-Xylene	6.36	6.637	70.54
o-Xylene	6.83	3.007	31.96
n-C9	7.28	0.085	0.90
n-Propylbenzene	8.12	1.106	10.80
3-Ethyltoluene	8.31	3.310	35.18
4-Ethyltoluene	8.31	3.310	35.18
1,3,5-Trimethylbenzene	8.43	1.363	14.49
2-Ethyltoluene	8.63	1.892	20.11
1,2,4-Trimethylbenzene	8.92	4.197	44.61
n-C10	9.27	1.318	14.01
Indan	9.66	1.293	13.74
n-C11	11.08	0.703	7.47
Naphthalene	12.23	1.275	13.55
n-C12	12.76	0.614	6.53
2-Methylnaphthalene	14.03	0.834	8.86
n-C13	14.31	0.608	6.46
n-C14	15.77	0	0
n-C15	17.14	0	0
n-C16	18.46	0	0
n-C17	19.70	0	0
Pristane	19.83	0	0
n-C18	20.85	0	0
Phytane	21.02	0	0
n-C19	21.93	0	0
n-C20	22.96	0	0
n-C21	23.94	0	0
n-C22	24.87	0	0
n-C23	25.88	0	0

Capillary Gas Chromatograph Characterization and Classification of Some Hydrocarbon Solvents and Alkyl Glycol Ethers

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Today's consumers and various industries enjoy a myriad of different commercial products, some of which are ignitable (including adhesives, sealants, insecticide carriers, jet fuels, charcoal starter fuels, and solvents). Once straight run petroleum distillates and simple blends of distillate products were commonly used. Presently, because companies are being more environmentally conscious, either through regulation or consumer demand, they have begun changing formulations to meet the challenge of being environmentally friendly. Recent petroleum products are manufactured through distillation, reforming, blending, desulfurization, hydrotreating, alkylation, extraction, cracking, and sometimes a second distillation to deliver the desired end use characteristics while providing a more environmentally friendly, less toxic product.

The examination of a small number of recent petroleum products and glycol ethers by gas chromatography/mass spectrometry (GC/MS) was conducted for pattern recognition and classification into six classes (one through six) based on the revised ASTM E-1387-90 method: light petroleum distillate, gasoline, medium petroleum distillate (MPD), kerosene, heavy petroleum distillate, and a miscellaneous class.

MATERIALS AND METHODS

A capillary column (DB-1, 15 m, 0.25 mm with 0.25 um film thickness, J & W Scientific, Folsom, CA) gas chromatograph with a mass spectrometer (Hewlett-Packard, 5897 GC/MS, San Jose, CA), having a linear flow of 1 ml/min at 100°C with a temperature program starting at 40°C for 2.00 minutes ramping at 25°C/min to 300°C for 2.00 minutes, a solvent delay of 0.10 minute and a National Bureau of Standards 75K MS library database were used for analysis. The injector temperature was 250°C with a source temperature of 200°C. The short solvent delay allowed collection of all peaks which chromatographed.

Neat standards were diluted 4:30 with carbon disulfide (J. T. Baker, Phillipsburg, NJ, Instra-Analyzed Reagent suitable for NIOSH methods 1003, 1500, and 1501 for hydrocarbons, Cat. #E350-01) with 1 uL injected into the GC/MS. The spectra were obtained under electron impact with the following settings: multiplier voltage 1889V, electron energy 70 eV, filament 300 mA, source pressure 8E-6, mass range 20 to 450 AMU, and transfer line 280°C.

RESULTS

Of the products analyzed, a larger number (34 of 50) now conform to the miscellaneous category of ignitable liquids (Table 1). Isoparaffins, cycloparaffins, and alkyl benzenes are represented in 42% (17/40) of the samples examined (the 10 glycol ethers excluded). Some products have the bell-shaped curve of a MPD or kerosene, but have no significant n-alkanes (360-66, Amber Lite Oil #111). The three dibasic esters (1, 2, and 5) have major peaks with retention times consistent with C10-C12 n-alkanes indicative of a MPD, but have no bell-shaped curve and are dioic acid dimethyl esters. Two glycol ethers (EM and EB) have single-peak retention times consistent with n-alkanes C6 and C9, respectively. Five products (Cyclo Sol 63, Cyclo Sol 53, SC Solvent 100, Super High Flash Naphtha, and TX 28 Solvent) have the five-peak group characteristic of gasoline with the remaining peaks of higher retention similar to gasoline. The jet fuel designated as JP-10 does not have the usual characteristic n-alkane peaks and bell-shaped curve associated with jet fuels, such as JP-8, but a single peak (octahydro-4, 7-methano-1H-indene) with two lesser peaks afterward.

CONCLUSION

Today, more than ever, fire debris analysts must be guarded in their interpretation of chromatograms from fire debris extracts due to the many new products being developed by petroleum and chemical industries. The unusual chromatographic patterns and unique chemical compounds these new products exhibit may give rise to more involvement of the GC/MS in identifying ignitable liquids from fire debris extracts and of the fire investigator to determine the nature of the identified product present, that is, intentional addition (gasoline in kitchen) or innocent presence (degreasing solvent).

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Table 1. Petroleum Liquid Products

#	Product Name (Abbreviated)	Source	Classification (ASTM)	C Range	Characterization
1	200-HT Mineral Spirits	Shell	Medium Petroleum Distillate	C9 - C12 Bell Shape Curve	C10, C11, C12 n-Alkanes
2	360-66	Ryco Line	Miscellaneous	C9 - C11 Bell Shape Curve	No Significant n-Alkanes From C8 - C12
3	Amber Lite Oil #111	Shell		C10 - C16 Bell Shape Curve	No Major Alkanes - Kerosine Range
4	Arcosolve PTB	ARCO	Miscellaneous	Single Peak Between C8 and C9	1-t-Butoxy-2-Methoxyethane
5	Aromatic 100	Exxon	Miscellaneous	C9 - C10	C1 - C3 - Aklyl Benzenes
6	Aromatic 200	Exxon	Miscellaneous	C11 - C16 No Bell Curve	Naphthalenes and Indenes
7	BT-67	Shell	Light Petroleum Distillate	C6 - C8 With Large C7	Isopars, Cycloparaffins, Toluene
8	Blazo Fuel	Chevron	Light Petroleum Distillate	C6 - C8 With Large C7	Isopars, Cycloparaffins, Toluene
9	Carburator Spray Cleaner	STP	Miscellaneous	C8 - C9	Isopropanol, Xylenes, Ethyl Benzene
10	Chemrite Choke & Carburator Cleaner	Chemrite Corp.	Miscellaneous	C8 - C9	1,1,1-Trichloroethane, Xylenes, Ethyl Benzene
11	Cyclo Sol 63	Shell	Miscellaneous	C9 - C13 No Bell Curve	C3 and C4 Alkyl Benzenes, Naphthalene
12	Cyclo Sol 53	Shell	Miscellaneous	C9 - C10	C3 and C4 Aklyl Benzenes, Xylenes
13	Dibasic Ester - 1	Dupont	Miscellaneous	Rt of n-Alkanes C10 - C12	C4, C5, C6 Dioic Acid, Dimethyl Ester
14	Dibasic Ester - 2	Dupont	Miscellaneous	Rt of n-Alkanes C11, C12	C5 and C6 Dioic Acid, Dimethyl Ester
15	Dibasic Ester - 5	Dupont	Miscellaneous	Rt of n-Alkane C11	C5 Dioic Acid, Dimethyl Ester
16	Glycol Ether DB	Union Carbide	Miscellaneous	C11 - C12	2-(2-Butoxyethoxy)-Ethanol
17	Glycol Ether DM	Union Carbide	Miscellaneous	C9 - C10	2-(2-Methoxyethoxy)-Ethanol
18	Glycol Ether DP	Union Carbide	Miscellaneous	C10 - C11	Propylene Glycol Diethyl Ether
19	Glycol Ether DPM	Union Carbide	Miscellaneous	C10 - C11	2-(Methoxy-Methylethoxy)-Propanol
20	Glycol Ether EB	Union Carbide	Miscellaneous	Rt of n-Alkane C9	2-Butoxy-Ethanol
21	Glycol Ether EE	Ashland	Miscellaneous	C7 - C8	2-Ethoxy-Ethanol
22	Glycol Ether EE Acetate	Ashland	Miscellaneous	C8 - C9	Ethylene Glycol Monoethyl Ether Acetate
23	Glycol Ether EM	Ashland	Miscellaneous	Rt of n-Alkane C6	2-Methoxy-Ethanol
24	Glycol Ether PM	Union Carbide	Miscellaneous	C6 - C7	1-Methoxy-2-Propanol
25	Glycol Ether TPM	Union Carbide	Miscellaneous	C12 - C13	1-[2-(2-Methoxy-1-Methylethoxy)-1-Methylethoxy]-2-PrOH

Table 1. Petroleum Liquid Products (Continued)

#	Product Name (Abbreviated)	Source	Classification (ASTM)	C Range	Characterization
26	Heavy Detergent Feedstock Amber 190	Shell	Miscellaneous	C9 - C19 No Bell Curve	No Doublet @ C17/C18, Mostly C13 - C19
27	Hi-Solv 15	Ashland	Miscellaneous	C10 - C12 No Bell Curve	C3, C4, C5 Alkyl Benzenes
28	Isopar M	Exxon	Miscellaneous	C11 - C15 Bell Shape Curve	Isoparaffins of C9, C10, C11, C12
29	Isoparaffin 370	Chevron	Miscellaneous	C9 - C12 No Bell Curve	Isoparaffins of C7?, C8, C10, C11?
30	Mineral Spirits 140 EC	Shell	Medium Petroleum Distillate	C10 - C12 Bell Shape Curve	C11 and C12 n-Alkanes
31	Paint Thinner Mineral Spirits	Bortzoil Products	Medium Petroleum Distillate	C8 - C12 Bell Shape Curve	1,1,3-Trimethyl Cyclohexane, C9, C10, C11
32	Parts Cleaner/Stoddard Solvent	Chemical Commodities	Medium Petroleum Distillate	C9 - C12 Bell Shape Curve	C10, C11 n-Alkanes
33	Petroleum Ether	EM Science	Miscellaneous	Single Peak	Pentane
34	Petroleum Naphtha	Shell	Kerosine	C9 - C16 Bell Shape Curve	C10, C11, C12, C13, C14 n-Alkanes
35	RAM 904	RAM Prod., Inc.	Miscellaneous	C7 - C12 No Bell Curve	Cycloparaffins, C3 - C5 Alkyl Benzenes to Indenes
36	SC Solvent 100	ChemCentral	Miscellaneous	C9 - C11 No Bell Curve	Xylenes, Alkyl Benzenes Consistent With Gasolines
37	SC Solvent 450	ChemCentral	Medium Petroleum Distilate	C8 - C13 Bell Shape Curve	C9 - C12 n-Alkanes
38	STP Super Concentrated Fuel Injector Cleaner	First Brands Corp.	Kerosine	C9 - C16 Bell Shape Curve	C10, C11, C12, C13, C14 n-Alkanes
39	Shell Sol 142 HT	Shell	Medium Petroleum Distillate	C10 - C12 Bell Shape Curve	C11 and C12 n-Alkanes
40	Shell Sol 340 HT	Shell	Miscellaneous	C9 - C11 Bell Shape Curve	C10 Only Significant n-Alkane
41	Solvent G	Shell	Miscellaneous	C10 - C12 No Bell Curve	C4 Alkyl Benzenes
42	Super Hi Flash Naphtha	Unocal	Miscellaneous	C9 - C11 No Bell Curve	Xylenes, Alkyl Benzenes Consistent With Gasolines
43	TS-28 Solvent	Shell	Miscellaneous	C9 - C11 No Bell Curve	Xylenes, Alkyl Benzenes Consistent With Gasolines
44	Tolu-Sol WHT Naphtha-25	Shell	Light Petroleum Distillate	C5 - C8	Cycloparaffins/Isoparaffins, C7 n-Alkane, Toluene
45	Treat-All Fuel Additive	JMC Chemical Co., Inc.	Light Petroleum Distillate	C4 - C8	i-Propanol, 2-Methoxyethanol, Methyl Isobutyl Ketone
46	VM & P Naphtha EC	Shell	Light Petroleum Distillate	C7 - C9	C8 n-Alkane Only
47	VM & P Naphtha HT	Shell	Light Petroleum Distillate	C7 - C9	C8 n-Alkane Only
48	n-Propyl Acetate	Ashland	Miscellaneous	C7 Retention Time	n-Propyl Acetate
49	JP-8	Military	Kerosine	C9 - C16 Bell Shape Curve	C10, C11, C12, C13, C14 n-Alkanes
50	JP-10	Military	Miscellaneous	C10 - C11 No Bell Curve	Major Peak: Octahydro-4, 7-Methano-1H-Indene

Gasoline Comparison By Capillary Gas Chromatography and Computer-Aided Pattern Recognition

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Accelerants recovered from the scene of a suspected arson are often submitted to the forensic laboratory for comparison to known standards or samples recovered from a suspect. Typically, these samples are compared by overlaying the chromatographic profiles or by evaluating peak ratios from selected regions of the chromatogram. Mass spectrometry is also used to identify key components and compound classes characteristic of various accelerants.

Typical gasoline samples contain approximately 400 components. Variability is introduced by such factors as the source of the crude oil, seasonal and regional environmental regulations, octane rating, additives, and the mixing of gasoline at tank farms, vehicles, and service stations.

MATERIALS AND METHODS

Chromatography was performed using a Hewlett-Packard Model 5890 Gas Chromatograph with a flame ionization detector equipped with 5673A Automatic Sampler with Tray and Nanoliter Adaptor (Hewlett-Packard, Avondale, PA). A 60 m, 0.25 mm ID, DB5, with a 1.0 u film thickness (J & W Scientific, Folsom, CA) was programmed from 30°C (1 minute) at a rate of 4°C/min. to 230°C (1 minute).

Data acquisition and processing were carried out using a Model 2600 Series Chromatography Data System (PE-Nelson Analytical, Inc., Cupertino, CA) and Computer Aided Pattern Recognition and Identification (CAPRI) software (Analytical Automation Specialists, Baton Rouge, LA).

In the first step, the computerized profile matching software segments the chromatogram into ten sectors and evaluates the number of peaks, retention times, peak heights, and total area in each sector. A peak-by-peak comparison is then performed. A factor score based upon 100 being a perfect match is created and the fits to library reference spectra are ranked.

RESULTS AND DISCUSSION

The long-term stability in the peak areas was determined to be 2.0% while the retention time stability ranged from 0.01% to 0.04% over the 60-minute chromatographic analysis time.

To evaluate the reliability of the computerized segmental chromatographic software, five samples were analyzed in triplicate and then compared to each other. The self-match averaged a score of 99 (range 98 - 100) while the second best match averaged a score of 57 (range 45 - 68).

To validate the method we have performed an analysis of 50 different gasoline samples purchased in northern Virginia and prepared a library. As shown

in Table 1, the comparison of a series of five blind unknowns to the library showed a correct first match for each sample. Figure 1 shows the chromatographic profiles for the third blind unknown sample and the top three matches.

Samples of gasoline weathered to 10%, 25%, and 50% volume were also matched by comparing the C8 - C13 region of the chromatogram. A small library of common accelerant has also been prepared which allows comparison to an unknown sample.

CONCLUSION

The combination of capillary gas chromatography and computer-aided pattern recognition can aid the forensic examiner in the comparison of neat gasoline samples. A library of partially-weathered samples as well as common accelerant can also be used to aid in the identification of unknown samples.

Table 1. Validation Study: Analysis of Blind Unknown Gasolines

Unknown	Actual Match	Library Match*	Match Score
A	CST24	CST24	97
		BSW15	81
		BSO42	79
B	TRB31	TRB31	98
		AUT29	63
		BRW13	60
C	ERB34	ERB34	95
		GUT8	57
		EUB35	34
D	BUW14	BUW14	96
		CUT23	95
		BUO41	94
E	UST49	UST49	97
		SSW3	28
		BSO42	28

*Listing of three best matches using CAPRI in decreasing order. The sample identity was coded using the brand, type, and location.

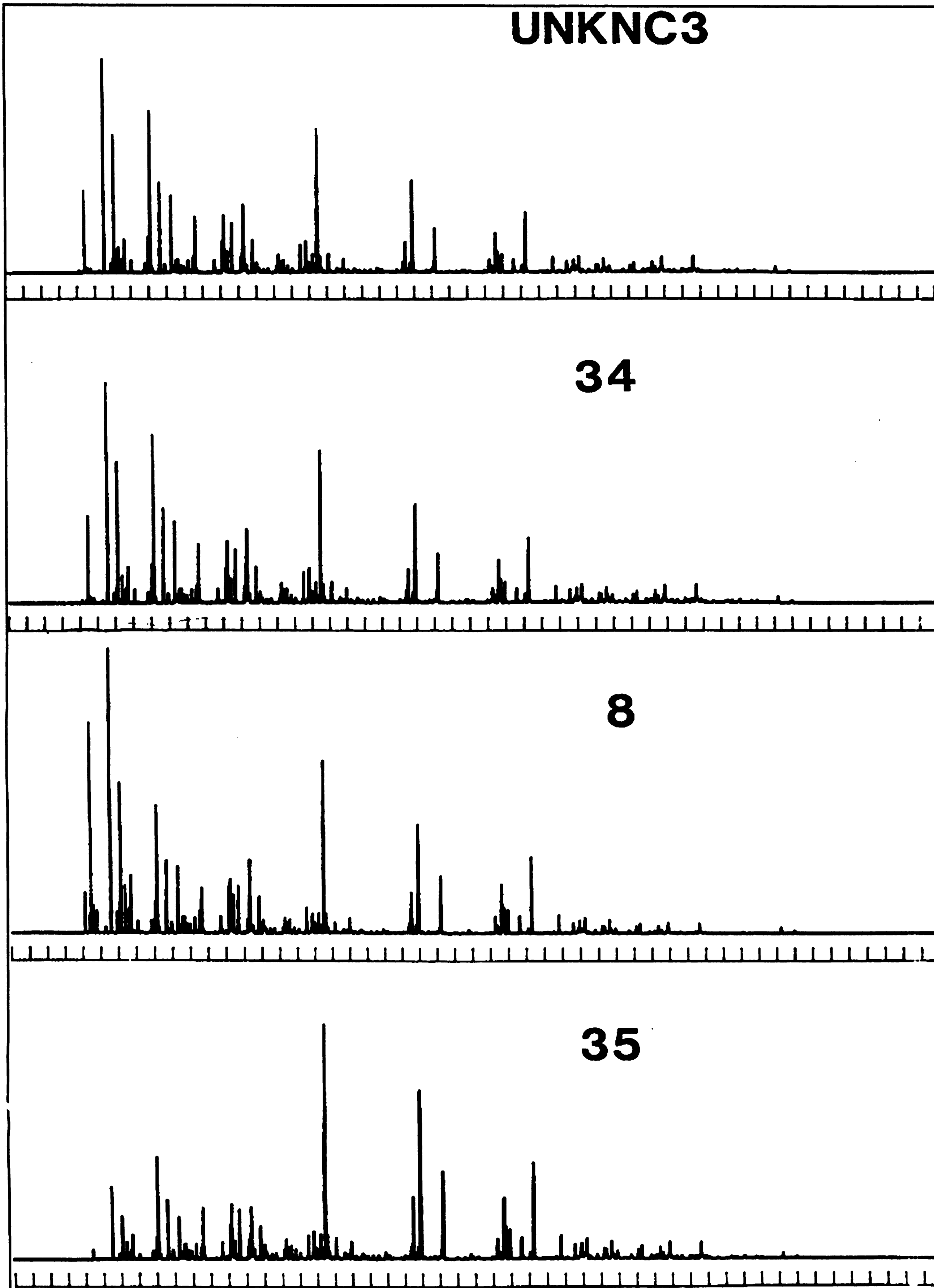

Figure 1. Chromatographic profiles for Unknown C (Table 1) and top three computer-aided pattern matches. Match scores for samples 34, 8, and 35 were 95, 57, and 34, respectively.

An Evaluation of Multiple Extractions of Fire Debris By Passive Diffusion

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Multiple extractions of various accelerants using commercially produced activated charcoal strips were studied to determine the reproducibility of data obtained by subsequent extractions. The extraction of three accelerants were evaluated: 50% evaporated gasoline, Rickett-Colman's formulation of Gulf Lite Charcoal Starter (a mixture of a medium range isoparaffinic mixture and kerosene), and SAM (Standard Accelerant Mixture of 50% evaporated gasoline, kerosene, and diesel fuel). Each accelerant was tested at three volumes: 1.0 uL, 15.0 uL, and 1 ml; and with two matrices: Kimwipes and burned debris (carpet, pad, foam, and wood). The accelerants were added to the substrates in individual quart cans and extracted with activated charcoal for 16 hours at 60°C. Eight hours after the initial extraction, the samples were re-extracted under the same conditions. The samples were analyzed by GC/MSD.

The most significant factors in multiple extractions is the type and volume of the accelerant present. Samples with large volumes of accelerant provided similar data in each extraction. Samples with smaller amounts of accelerants were prone to produce different profiles in multiple extractions. The second profile may differ from the first in one of three ways. First, the accelerant may be completely removed by the first extraction, therefore, no identification could be made in subsequent extractions. This is more likely to occur when minute amounts of accelerant are present on simple matrices. Second, components of the accelerant may be removed preferentially in the first extraction due to displacement of the more volatile components (Figure 1). This could occur in samples where the volume of the accelerant just exceeds the capacity of the strip. Once the strip reaches capacity, displacement of the lighter component occurs (Tindall and Dietz 1994). The profile of the accelerant in the sample in the second extraction is shifted to the more volatile components. Finally, components of accelerants may be preferentially removed in the first extraction due to differences in volatility (Figure 2). This may be seen in samples which contain Class 5 accelerants in small to moderate volumes. The heavier molecular weight components are the least volatilized and adsorbed in the first extraction, resulting in a profile emphasizing the heavier components in the second extraction.

The presence of a complex matrix affects the extraction by inhibiting the volatilization of the accelerants. Thus, the initial extraction is less efficient and provides more reproducible profiles. Profiles of accelerants in samples which contain less complex matrices tend to be more significantly altered by the initial extraction.

Passive diffusion is an essentially nondestructive technique which performs well for extraction and re-extraction in most situations. However, it is an extraction and, therefore, (by definition) alters the sample by removing a select portion of its contents. Conflicting results may occur when smaller amounts of accelerants are present.

REFERENCES

Tindall, R. and Dietz. W. R. The effects of time, temperature, strip size, and concentration in use of activated charcoal strips in fire debris analysis. *46th Annual Meeting of the American Academy of Forensic Sciences*, San Antonio, TX, February 1994.

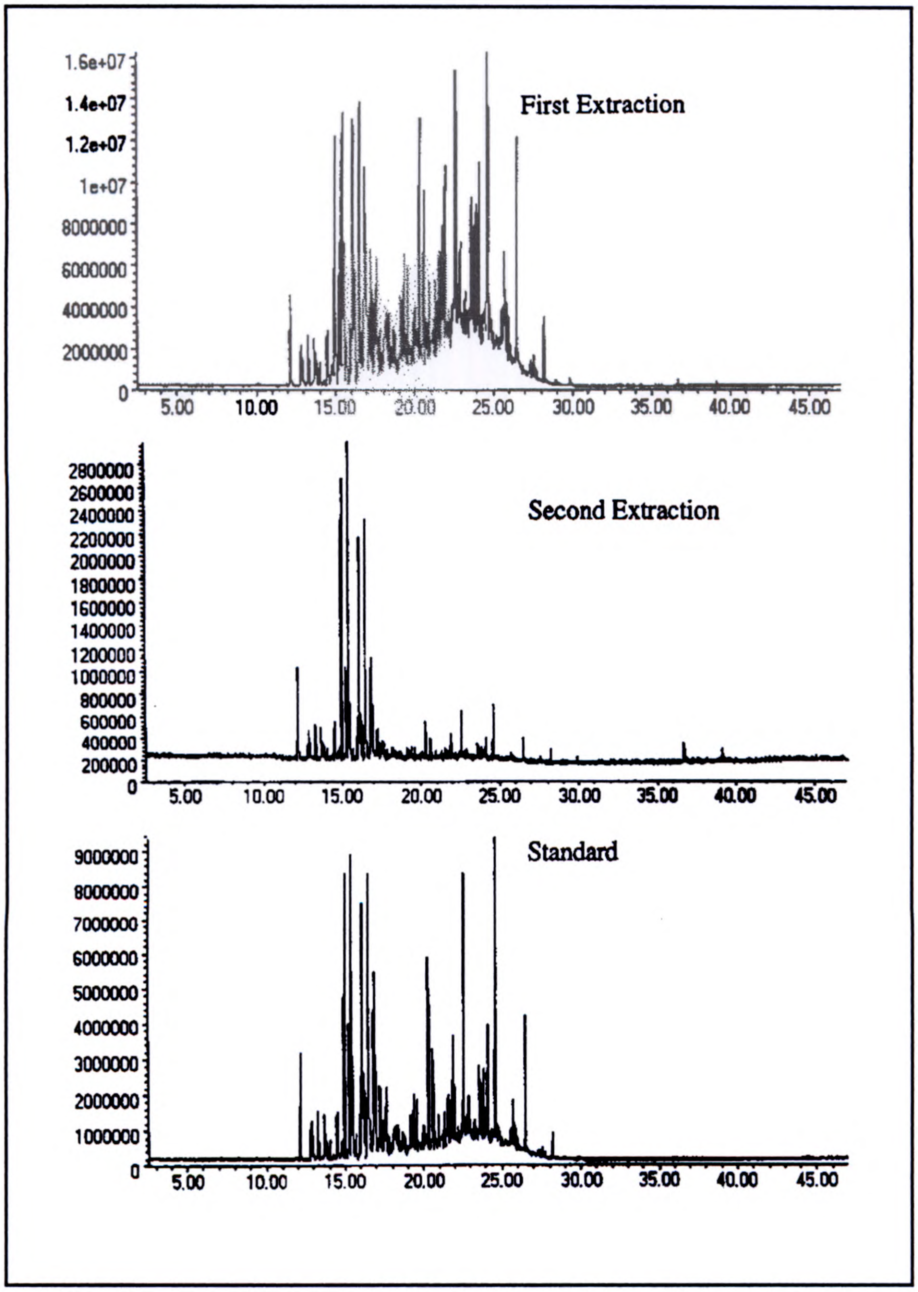

Figure 1. Chromatograms obtained from extractions of 15 uL of Reckitt-Coleman's formulation of Gulf Lite Charcoal Starter. Extracted by passive diffusion on 3/8" diameter activated charcoal discs at 60°C for 16 hours. Gulf Lite standard prepared by diluting 10 uL in 1 ml of carbon disulfide.

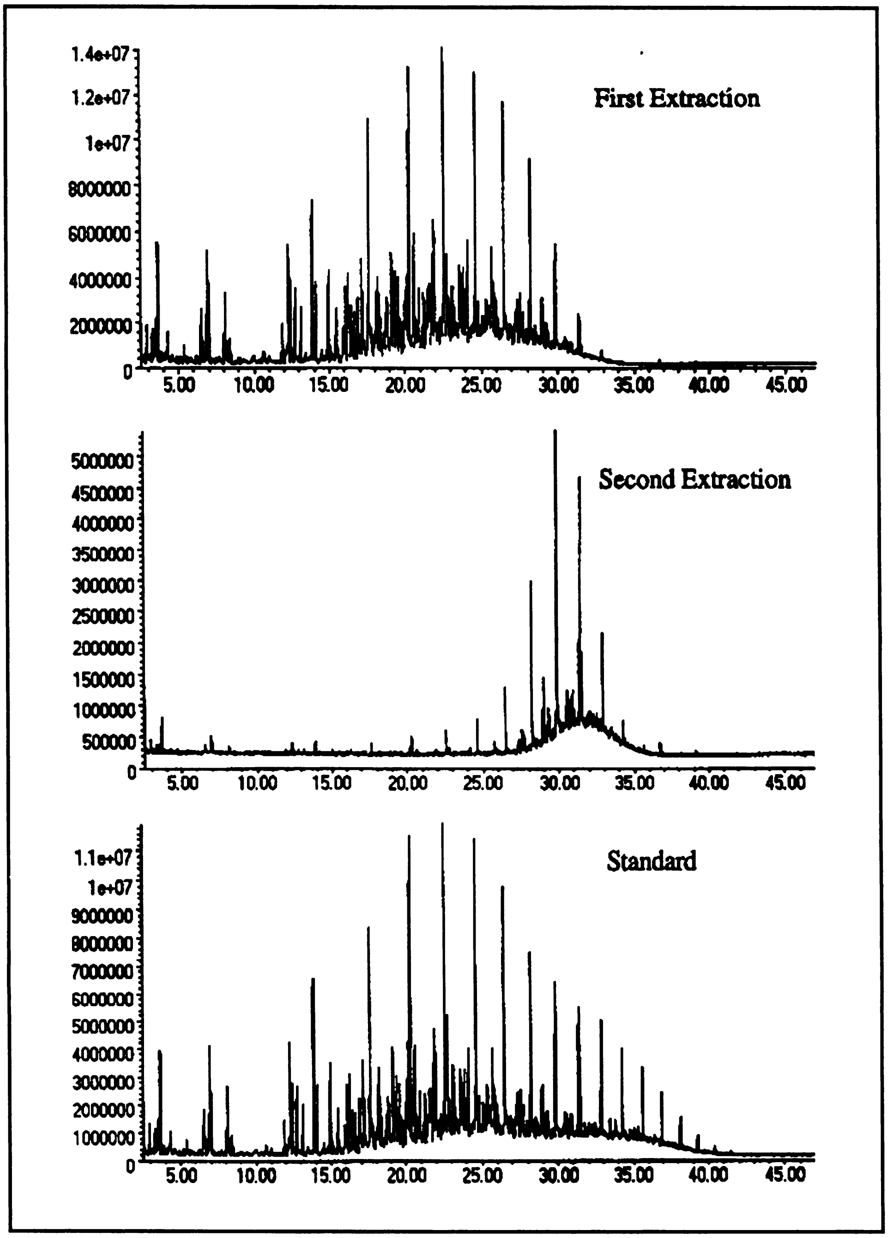

Figure 2. Chromatograms obtained from extractions of 15 uL of SAM (Standard Accelerant Mixture). Extracted by passive diffusion on 3/8" diameter activated charcoal discs at 60°C for 16 hours. SAM standard prepared by diluting 10 uL in 1 ml of carbon disulfide.

The Effects of Fire Suppressants on Fire Debris Analysis

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It was brought to the attention of these authors that products are being added to water to aid in the suppression of fires. Some manufacturers claim these suppressants "breakdown" ignitable liquids. A study was performed to determine if this breakdown process affects the chemist's ability to identify ignitable liquids for analysis by gas chromatography/mass spectrometry (GC/MS). The products tested were: Aqueous Film Forming Foam (BST Victor Chemical Company, Long Beach, NY), Micro Blaze Out (Verde Environmental, Houston, TX), Fuel Buster (FSI, Peachtree City, GA), Gold Crew (ARA Chemical, Inc., San Diego, CA), and Silvex (Ansoil Fire Protection, Marnett, WI).

MATERIALS AND METHODS

First the background of each suppressant was established. This was accomplished by charcoal strip extraction followed by GC/MS analysis.

A Pro-Tek (Pro-Tek Systems, Cromwell, CT) charcoal strip was suspended in a glass jar containing the sample in question. The jar was heated at 85°C for 17 hours then allowed to cool. The charcoal strip was removed and placed into a vial of diethyl ether. A Hewlett-Packard 5890 Series II GC interfaced with a Hewlett-Packard 5972 MS was used for analysis. The column used was a 25 meter methylsilicone column with a diameter of .2 mm and film thickness of .33 μm. The GC had an initial temperature of 50°C and initial hold time of 2 minutes. The temperature was then ramped at 12°/min to a final temperature of 275°C and held there for 4 minutes.

Two sets of 15 samples were prepared using each product—one set with gasoline and one with diesel fuel. Samples were prepared by introducing one milliliter of the ignitable liquid to a small square of carpet which was ignited. After a 30-second burn, the carpet samples were extinguished with one of the fire suppressants. The samples were sealed in glass jars and stored at room temperature until charcoal strip extraction. Triplicate extractions were performed immediately, then at 1 week intervals for 4 weeks.

RESULTS

None of the products tested had a detrimental effect on the ignitable liquids. After 4 weeks, gasoline and diesel fuel patterns were still present and the substances were easily identified. However, there was one product that could present a problem to the unwary chemist. Silvex® produced a very large peak (up to 90% of the total peak area). This peak was identified by the library search, but not yet confirmed by our laboratory, as 2.2 butoxyethoxyethanol. Since most GC/MS systems normalize the total ion chromatogram (TIC) to the largest peak, the ignitable liquid pattern was obscured. Upon initial examination, the gasoline and diesel patterns were not apparent in some of the samples. It was necessary to enlarge the TIC, ignoring the largest peak, to see the ignitable liquid pattern.

CONCLUSIONS

From this study, these authors have concluded that fire suppressants do not alter ignitable liquids in a manner that prevents their identification by GC/MS analysis.

A Fire Investigation Involving Combustion of Recycled Polyethylene Films

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A suspicious fire in an industrial estate broke out among 200 tons of recycled polyethylene carrier bags, wrapping, and packing materials.

Polyethylene bales of 200 kg were stacked up in a warehouse to be reprocessed as polyethylene beads to later be stretched into litter bin bags. The fire went on for 6 hours; all of the stock burned down. What little remained was in melted and hardened flows and hills. Two thousand square meters of the industrial building was destroyed. In the contiguous workshop, a narrow intermediary zone was slightly concerned by the fire spreading. A second fire appeared to have broken out on its own among machinery and buffer stocks. Attention was attracted by a bale loaded on a forklift truck (See Figures 1 and 2). It had undergone thermal disorders. A weak signal was recorded by our portable sniffer. The hard superficial polyethylene layer was cut through with a chain saw and a better signal came up. This procedure was applied onto the little hills remaining.

ANALYTICAL FINDINGS

Gasoline was recovered from beads and plastic films in the following experimental procedure.

Sample Preparation

Beads and films collected were placed in one-liter airtight glass jars and heated up in an oven at 80°C for 20 minutes. A gas syringe was used to collect 0.5 ml of headspace from the heated containers through a septum. Two comparison matrix samples were designed to evaluate polyethylene influence on the layout of question chromatograms—one with straight beads and films, the other with partially burned and molten materials. The air samples were immediately injected into a gas chromatograph.

Apparatus

All samples were examined using a Perkin-Elmer 8410 gas chromatograph on a splitless mode/ FID detector. The column was a nonpolar fused silica column, Petrocol DH (Supelco, Inc., Belefonta, PA) 100 m, 0.25 mm internal diameter, 0.5 micron film thickness. Helium was used as carrier gas at a linear velocity of 14 cm/sec. The oven temperature was programmed to 60°C (1 minute) to 250°C at 2°C/min for 30 minutes.

Results

The two matrix sample chromatograms did not show interference after 20 minutes at 80°C; chromatograms remained flat. Sample chromatograms were superimposed on a reference gasoline chromatogram on a light box. The overall shape for four samples presented very little variation from reference gasoline even in the early eluting portion with small decrease in the peak occurrence. No additional peaks appeared as expected for polymers such as polyethylene (See Figure 3)

CONCLUSION

Crime scene observation led us to establish the existence of two independent zones where seats of fire broke out. They were separated by a narrow strip where machinery remained untouched or with little

damage. No physical link existed between them except the incombustible roofing. Multiplicity of fire seats could be clearly established. Analysis revealed the presence of gasoline in four of our semi-burned and molten polyethylene samples made on site. Chromatograms obtained were very close to reference gasoline with no interference from polyethylene matrix. The accelerant preservation was mainly due to the formation of an upper hard airtight crust on the material surface while cooling down. Trapped chemicals were prevented from evaporation.

Figure 1.

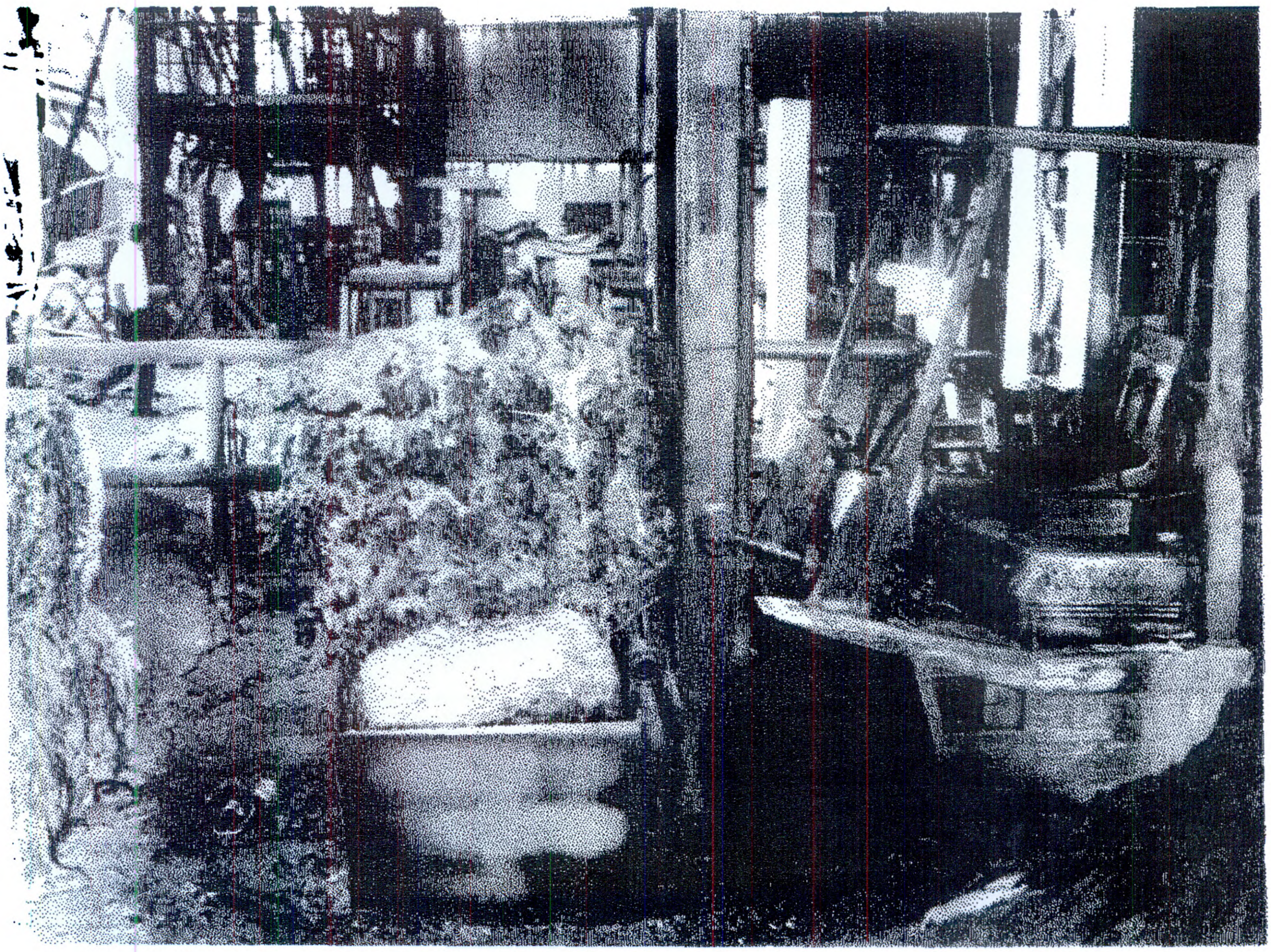
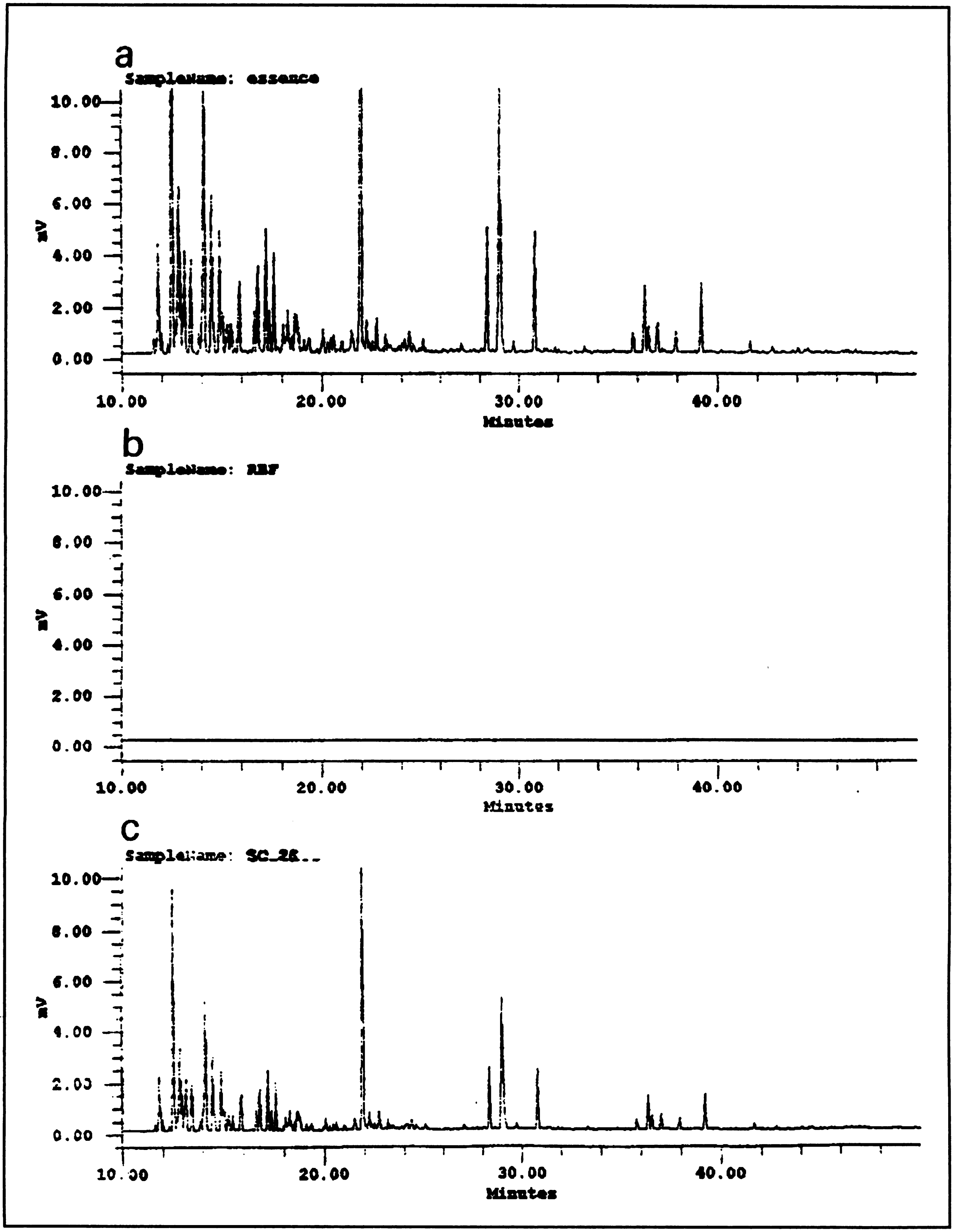


Figure 2.



a
SampleName: essence
10.00
8.00
6.00
4.00
2.00
0.00
mV
10.00
20.00
30.00
40.00
Minutes
b
SampleName: REF
10.00
8.00
6.00
4.00
2.00
0.00
mV
10.00
20.00
30.00
40.00
Minutes
c
SampleName: SC_2&
10.00
8.00
6.00
4.00
2.00
0.00
mV
10.00
20.00
30.00
40.00
Minutes

Figure 3.

Pattern Recognition of Bacteria-Degraded Accelerants in Soil

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During the course of arson investigations, soil samples are often submitted to the laboratory to be analyzed for the presence of flammable or combustible liquids. When gasoline is collected in a soil medium (or other substrate which may have concentrations of bacteria), the bacteria inherent in the soil can affect the accelerant. This could result in altering the chromatographic appearance of the gasoline upon analysis (Mann and Gresham 1990). Of further interest was to also determine the chromatographic appearance of other types of accelerants, namely, medium petroleum distillates (MPD) and heavy petroleum distillates (HPD) after exposure to soils. These chromatograms could then be used as reference or comparison standards for aid in casework evaluations.

Aliquots of gasoline, a MPD (mineral spirits), and a HPD (fuel oil #2) were each separately added to clean metal cans containing soil. Each accelerant type was added to three different types of soil. The soils ranged from dark and slightly damp to dry and sandy. Three different soil types were used to try to ensure some bacterial activity in at least one of them. A control sample of each accelerant type was placed on paper toweling and placed in the metal cans. The cans were kept at room temperature in the laboratory.

The samples were analyzed on the day of preparation and at 1 week, 2 weeks, and 3 weeks after preparation (4 cans of each were prepared on day 1, so that no can was analyzed more than once). Dynamic heated headspace technique employing activated charcoal tubes was used to extract the accelerants from the soil. The can was placed in an oven of 90°C for 30 minutes with a vacuum line attached to a charcoal tube placed through the lid of the can. An inlet air charcoal tube was also placed in the top of the can. Carbon disulfide (CS_2) was used to elute the sample from the charcoal tubes. One-microliter injections of the samples were run on a Perkin Elmer 8500 gas chromatograph (GC). The column was a 15-meter nonpolar bonded methyl silicone capillary column with a .25-mm I. D. and a 1.0-micron film thickness. The carrier gas was helium at 1-ml/min with a split ratio of 25:1. The injector temperature was 275°C and the FID detector temperature was 310°C. The temperature program was 50°C for 1 minute, 20°C per minute ramp to a 300°C hold for 5 minutes.

GC patterns of each of the soil and accelerant samples were examined. The control samples on toweling were also tested at the same intervals and their chromatograms examined. Of the three different soil types used, one in particular gave the most pronounced results. This was the soil that was a little darker and damper than the other two soils used.

No significant change was seen in the gasoline sample until the 2-week sampling. It was difficult to determine if the gasoline sample from this soil had degradation effect of the aromatics or was showing a typical evaporative/weathering pattern. The control sample of gasoline (on toweling) showed only a slight evaporative effect, but does not truly mimic the conditions inside the soil sample, such as moisture.

The MPD showed microbial degradation of the *n*-alkanes by week 2, and even more at week 3. The HPD had some diminished *n*-alkanes at the 1-week sampling, but was much more apparent at week 2 and week 3.

It appeared that the *n*-alkanes of the MPD and HPD were very affected in this soil sample, where the aromatics of the gasoline were effected to a lesser extent. Further testing would need to be done to determine the significance or validity of this observation. Mass spectral analysis using ion profiling would also be very useful in more closely observing the degradation changes in the different chemical classes or groups.

The patterns from these bacteria-degraded accelerants can aid in evaluating chromatograms. They can be used for comparison in casework where bacterial involvement may be a factor.

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Mann, D. C. and Gresham, W. R. Microbial degradation of gasoline in soil. *Journal of Forensic Sciences* (July 1990) 35(4):913-923.

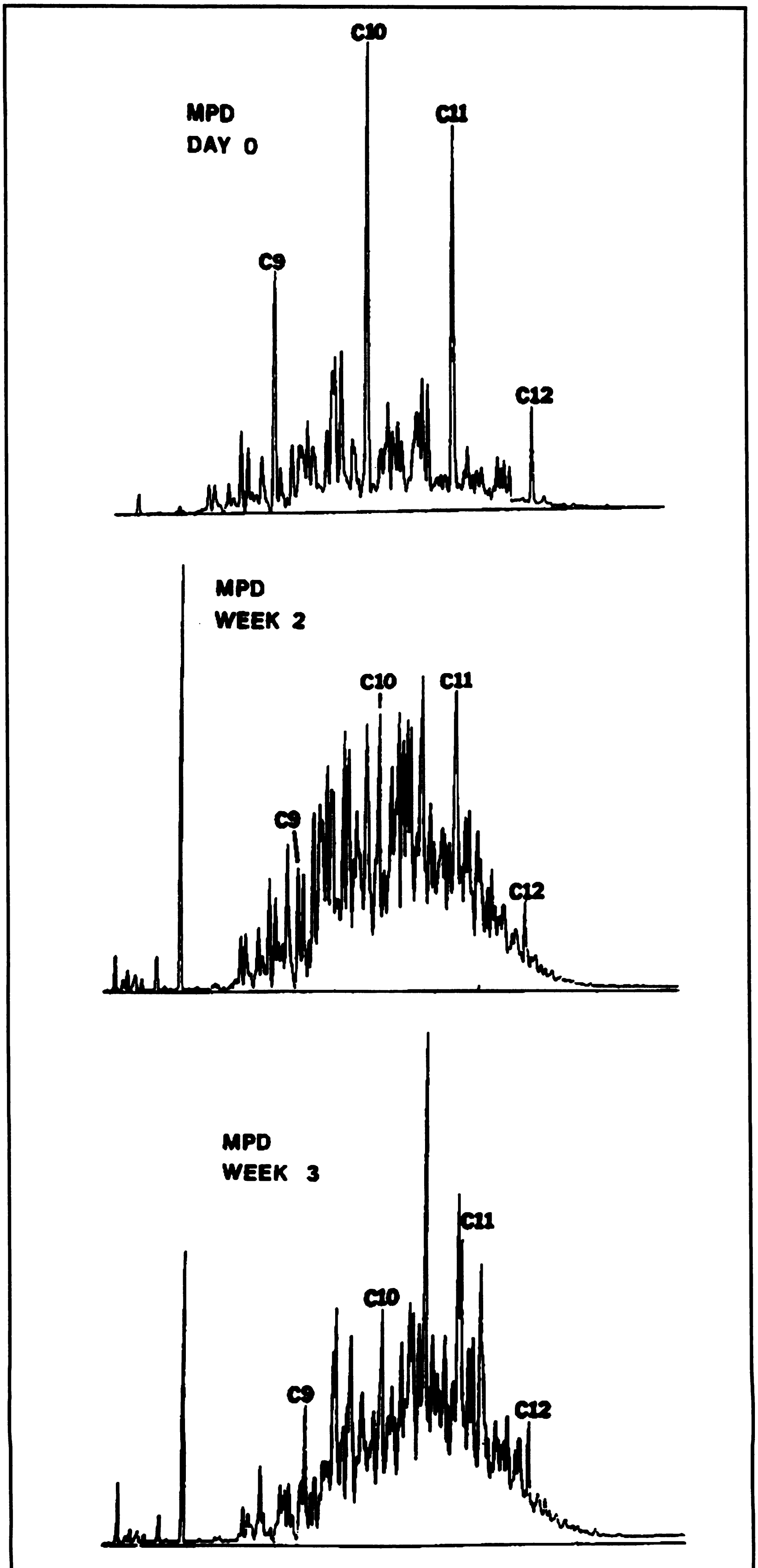
MPD
DAY 0
C9
C10
C11
C12
MPD
WEEK 2
C9
C10
C11
C12
MPD
WEEK 3
C9
C10
C11
C12

Figure 1.

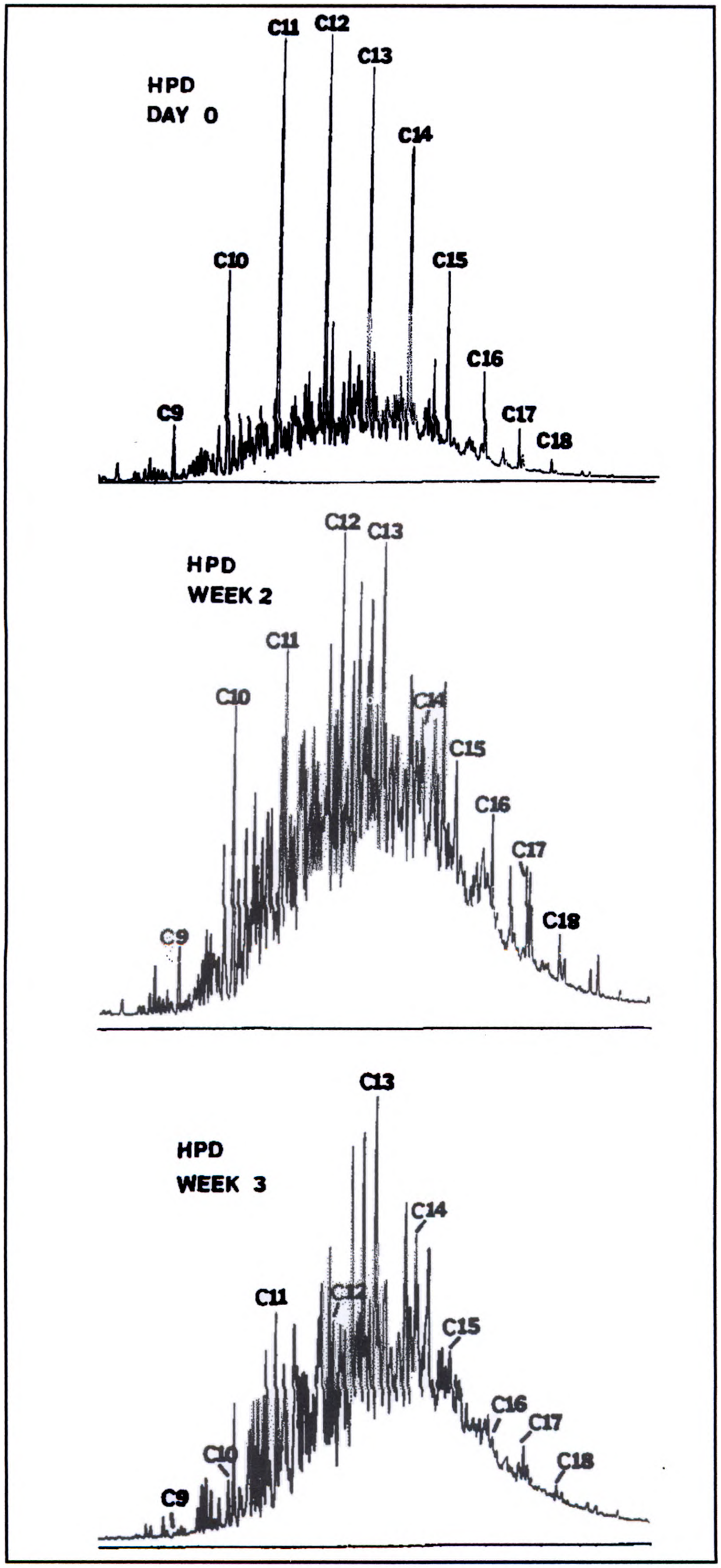
HPD
DAY 0
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
HPD
WEEK 2
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
HPD
WEEK 3
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18

Figure 2.

An Improved Method of Obtaining Ion Profiles from Ignitable Liquid Residue Samples

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This study was undertaken to improve the collection of extracted ion profiles from mass spectral data. Using the full scan method of collecting data frequently results in a higher detection limit relative to GC/FID and ion profiles with a noisy baseline or a baseline which is off the bottom of the scale. One goal of this study was to produce ion profiles with a more chromatographic appearance and another goal was to decrease the lower limit of detection. Ion profiling is also known as mass chromatography and has been used for fire debris analysis since it was first described by Smith (1982) and has been codified in ASTM E-1618, *Standard Guide for Ignitable Liquid Residues in Extracts of Fire Debris Samples by Gas Chromatography/Mass Spectrometry.*

MATERIALS AND METHODS

All samples were run on a Hewlett-Packard (HP) 5890 Series II gas chromatograph connected to a HP Model 5971A mass selective detector. Data analysis was accomplished using HP ChemStation software. The column was a 25 meter HP-1 0.2 mm I. D., 0.5 um film thickness, operated at an initial temperature of 60°C for 6 minutes, ramped at 20°C/min to 280°, and held at 280°C for 4 minutes. A 50:1 split ratio was used on 0.5 ul samples injected with an HP Model 7671 automatic liquid sampling system.

Comparisons were made between data collected using the scan method (33-300 amu) and the selected ion monitoring method, using the 15 ions collected as shown in Table 1. The effect of varying the dwell time for this group of ions was also studied. Dwell times of 10, 20, 50, 100, and 200 milliseconds were used. In addition, a special program looking only at Ion 57 was examined.

Weathered gasoline and kerosene, ranging in concentration from 1% down to 1 ppm dissolved in diethyl ether, were examined.

RESULTS

The use of the SIM mode of collecting data resulted in a significant decrease in the lower limit of detection. Identifiable ion profiles of the most important groups of gasoline compounds could be collected from samples containing 10 ppm gasoline, while it was necessary to have a concentration of 100 ppm of gasoline in order to obtain useful ion profiles when the data was collected using the full scan. When a special program designed to look strictly at Ion 57 was applied to kerosene, a concentration of 1 ppm could be detected as opposed to a concentration of 100 ppm required for the full scan method.

A dwell time of 50 milliseconds was found to be sufficiently low to allow for the resolution of the p-ethyltoluene shoulder on the m-ethyltoluene peak. Decreasing the dwell time resulted in slightly improved resolution, but slightly increased noise.

Use of the SIM method precludes obtaining individual mass spectra from a given peak, but in almost all cases, analysts are attempting to recognize a pattern of peaks; this can be accomplished at

concentrations equal to or less than those required for pattern production by GC/FID.

The SIM method of collecting data does not result in significantly larger signals, but there is a reduction in the background noise of between 1 and 2 orders or magnitude. The SIM ions selected result in a total ion chromatogram which very closely resembles that produced by the full scan. The reduction in the background noise provides selected ion profiles with a much cleaner and more chromatographic appearance than ion profiles extracted from full scans. A comparison of two profiles is presented in Figure 1.

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Table 1. Ions Collected in SIM Mode

amu	Ion
31	Alcohols
45	Alcohols
55	Alkenes
57	Alkanes
71	Alkanes
78	Benzene
83	Cycloalkanes
91	Xylenes, Styrenes
105	Cumenes
117	Indenes
119	Heavier Aromatics
128	Naphthalenes
131	Methylindenes
142	Methylnaphthalenes
156	Dimethylnaphthalenes

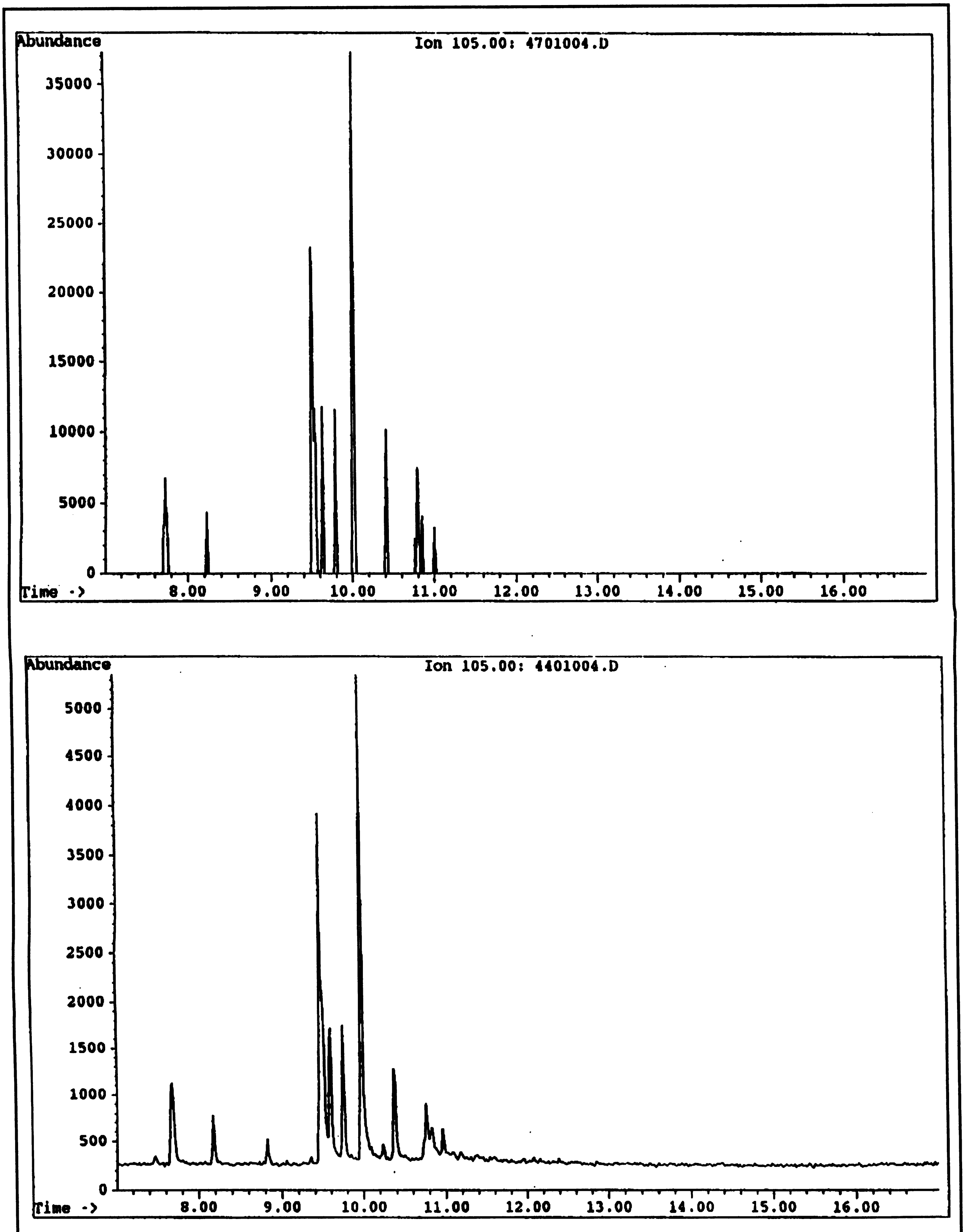

Figure 1. Comparison of cumene profile (Ion 105) from a sample of 100 ppm gasoline run in the full scan mode (top) and 10 ppm gasoline run in the selected ion monitoring mode (bottom).

An Encounter with an Isopar Formulation in a Suspected Arson Case

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Colorado Bureau of Investigation
Denver, CO

The purpose of this research was to characterize a relatively obscure isopar formulation which was encountered in a submission from a suspected arson case. Additionally, the author desired to qualitatively and quantitatively elucidate the composition of this mixture. The sample studied is a fuel source for decorative (votive style) lights and food-warming devices. The author also desired to compare this product with other commonly encountered commercial products which are currently used for the same purposes.

The isopar mixture, reference standards, and competitive products were all analyzed similarly by utilizing a Hewlett-Packard model 5890 series II gas chromatograph coupled to a model 5971A mass selective detector (Hewlett-Packard, Palo Alto, CA). A 12 m x 0.2 mm x 0.33 um (film thickness) HP-1 crosslinked methyl silicone gum capillary column was employed for all analyses. The temperature program for the analyses runs was 40°C initial with a 0.10 minute initial hold then ramped at 10°C/min to 210°C, then ramped at 15°C/min to 300°C, with a final hold of 2.0 minutes. The total run time was 25.10 minutes. The injection port was held at 250°C while the transfer line was 280°C. The extraction technique employed the activated charcoal strip (Dietz 1991). One ul of carbon disulfide (EM Industries, Gibbstown, NJ) was injected with helium being used as the carrier gas. Library searches were performed on the NBS 49K library supplied commercially by Hewlett-Packard with their Vectra QS/165 data station.

Laboratory analysis of the fuel cell revealed the presence of the previously unencountered isoparaffin mixture. This particular isopar displays three predominant constituents with two additional trace contributors. The fractions eluted in the region normally associated with products displaying a medium petroleum distillate (MPD) signature. Pyrolyzates are also often observed in this region. The mass spectral information of the three primary constituents indicates that they are consistent with dodecane ($C_{12}H_{26}$), tridecane ($C_{13}H_{28}$), and tetradecane ($C_{14}H_{30}$), respectively. A semiquantitative evaluation of their contributions to the mixture is 14%, 55%, and 30%, respectively. The two trace components account for the other 1%. The isopar formulation is in sharp contrast to other commonly encountered candle or lamp oils. These others either display the typical, and obvious, bell-shaped distribution pattern of a MPD or the single component (methanol) formulation.

Analysts should be cognizant of the fact that isopars of this type are not only commercially available, but are being employed in various establishments. The potential for this type of product being encountered as either an accelerant or as a contaminant should not be overlooked. The few constituents of such a mixture may easily be camouflaged by the matrix of pyrolyzate peaks commonly generated during a fire. Furnished with this information, arson investigators (be they scene investigators or laboratory analysts) should conduct thorough examinations of their samples to determine whether such an isopar may be a contributing factor in their respective cases.

REFERENCES

Dietz, W. R. Improved charcoal packaging for accelerant recovery by passive diffusion. *Journal of Forensic Sciences* (January 1991) 36(1):111-121.

A Study of the Effect of Extraction Temperature on the Class Identification of Flammable and Combustible Liquids by GC/MSD According to ASTM E-1387-90

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In the analysis of submitted fire debris when accelerant material is present, the analyst can conclusively determine class identification of flammable and combustible liquids utilizing gas chromatography/mass selective detector (GC/MSD) generated total and selected ion chromatograms from passive headspace concentration using charcoal/polymer strips (Protek Systems, Middletown, NY) according to the American Society for Testing Materials (ASTM) E-1387-90 and E-1413-91. This presentation will demonstrate how these procedures were used to select a minimum optimum extraction temperature for identification.

Carbon disulfide extracts of four commonly encountered known flammable or combustible liquids [namely, gasoline (class 2), mineral spirits (class 3), kerosene (class 4), and #2 diesel fuel (class 5)] were prepared at oven temperatures of 60°C, 70°C, 80°C, and 90°C utilizing 4 mm x 8 mm charcoal strips impaled on gem clips, secured with approximately 6 inches of cotton string, and suspended in lined metal quart paint containers. Each container received 2 Kimwipe tissues, 2.0 µl of the respective liquids, one charcoal strip, and was tightly closed. The containers were placed in the oven for approximately 16 hours. The charcoal strips were retrieved and extracted with 100 µl of carbon disulfide by gentle hand agitation for 2 minutes. One microliter aliquots of the extracts were injected into a GC/MSD composed of a Hewlett-Packard 5890 Capillary Gas Chromatograph and a Hewlett-Packard 5970 Mass Selective Detector. The column chosen was a DB-1 (J & W Scientific, Folsom, CA), 15 meter x 0.25 mm I. D. with 0.25 µm film thickness. Data was accumulated on a Hewlett-Packard Chem Station (HP-UX Series).

The examination of total and selected ion chromatograms revealed that an oven temperature of 60°C resulted in data which would satisfy ASTM requirements for identification of class 2, 3, and 4 products. The minimum optimum oven temperature of 70°C was required for the identification of the class 5 product by disclosing the presence of 5 consecutive n-alkane peaks C17 - C21. This identification was accomplished while minimizing the loss of

components necessary to identify class 2, 3, and 4 products. The examination of data from an oven temperature of 90°C displayed the characteristic loss of components, namely ethylbenzene, while enhancing the recovery of C21 and C22 alkanes.

This study has shown that the minimum optimum oven extraction temperature of 70°C will not hinder the detection of, and may actually enhance the ability to recover trace quantities at or near the lower limits of detection for passive headspace concentration of flammable or combustible liquids in fire debris.

REFERENCES

American Society for Testing Materials. *ASTM E-1387-90, Standard Test Method for Flammable or Combustible Liquid Residues in Extracts From Samples of Fire Debris by Gas Chromatography*. 1990.

American Society for Testing Materials. *ASTM E-1413-91, Standard Practice for Separation and Concentration of Flammable or Combustible Liquid Residues From Fire Debris Samples by Passive Headspace Concentration*. 1991.

An Improved Method for Using Activated Charcoal Strips in Accelerant Absorption/Elution Techniques

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The of activated charcoal strips in arson analysis by passive absorption/elution techniques is becoming more and more prevalent in crime laboratories. This method was first pioneered by William Deitz of the Bureau of Alcohol, Tobacco and Firearms (Deitz 1991) and has been taught at numerous arson analysis courses over the past several years. The basic methodology is simply to secure a strip inside a container of arson debris and heat the container. As the accelerants are driven off by the application of heat, they are absorbed by the strip and can be later removed with various solvents. Any accelerant recovered can then be identified by instrumental means.

The method developed involves the manufacture of paint can lids with alligator clips inverted on the inside. The alligator chips are soldered onto the bottom of the can lid. The strips can then be placed in the jaws of the clips and the lid placed on a can containing the debris. After the absorption phase of the analysis, the strip is removed. The can lid is then washed with hot water and placed in an oven at 100°C for at least 1 hour to ensure there is no carryover of accelerants. This method alleviates the problem of trying to find a way of suspending the strips each time a sample is to be ran and not having them fall into the debris.

This method has been used for the past several years in the Colorado Bureau of Investigation Pueblo Laboratory with no carryover problems. It has been found to be a useful and time saving method in accelerant absorption/elution.

REFERENCES

Dietz, W. R. Improved charcoal packaging for accelerant recovery by passive diffusion. *Journal of Forensic Sciences* (January 1991) 36(1):111-121.

Nondestructive Testing of Appliances for Accelerant

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This research was done to determine the best method of using a DFLEX card (Albrayco Laboratories, Inc., Cromwell, CT) for collecting accelerant vapors from appliances that are suspected of causing a fire. The DFLEX card is a charcoal strip encased in a membrane and metal case that will adsorb petroleum vapors and alcohol. Testing included heating of an appliance with a DFLEX card to determine if heating is necessary and more reliable, as well as the card's sensitivity to different types of petroleum and alcohol products.

In this research, two tests were conducted along with three actual house burns where appliances were set on fire with accelerant. In Test #1 three coffee makers and three televisions were introduced with .125 ml of a 50/50 mix of diesel fuel and gasoline; they were set on fire for 15 minutes, and doused heavily with water. A fourth television/coffee maker was burned with no accelerant as a control sample. The appliances were then placed in separate heavy plastic bags with a DFLEX card and heated at different temperatures for 48 hours. The DFLEX cards were removed from the bags and placed in quart evidence cans and sent to the laboratory (see Table 1). In Test #2 three coffee makers were introduced to .5 ml of each of the following accelerants: alcohol, gasoline, and diesel fuel. The accelerants were placed inside each coffee maker and then placed inside a plastic bag, unburned, with a DFLEX card for 16 hours at various temperatures. The actual house fire tests were conducted as part of an arson course where two coffee makers and one television had gasoline, charcoal lighter fluid, or camping stove fuel placed on them; they were set on fire and extinguished after the room flashed over. The appliances were then placed in a bag with a DFLEX card and sealed for a minimum of 48 hours at room temperature.

After sampling all appliances with the DFLEX card, all cards were sent to the laboratory for analysis. Of the nine appliances burned with accelerant, two had no detectible accelerant. The DFLEX card was very good at collecting accelerant vapor, including alcohol. The diesel fuel was detected, but not as well as gasoline. Heating the appliance tended to reduce the quality of the accelerant found and sometimes increased the background on the gas chromatogram from plastic byproducts. In Test #2 where unburned coffee makers were used with an accelerant of alcohol, gasoline, and diesel fuel, the best sample came from the room-temperature tested appliance. The relative concentration of accelerant in each item was determined by the total area of the gas chromatogram (see Table 2). In the actual house burns, all three appliances had accelerant detected and identified. This was a blind test for the laboratory.

CONCLUSION

Testing results indicate that the use of a DFLEX card or other similar device placed inside a large heavy plastic bag with the suspected appliance is a good method of testing for accelerant without destroying the appliance for further examination by other experts. It is recommended that an appliance suspected of causing a fire be tested for accelerant. As soon as possible, the suspected appliance should be placed inside a heavy large sealed plastic bag with a DFLEX card or similar device and left to sit for 48 - 96 hours at room temperature. If the storage area to be used is cold, the appliance should be placed inside a metal storage cabinet with a space heater at 100°F. The DFLEX card should then be removed and placed in an evidence can and sent to the laboratory for analysis. Note: If appliance would tear the bag, it is suggested that the item be placed in a clean unused

box and then placed in the bag with the DFLEX card (remembering to then sample a box with a card for control purposes). The advantage of this method is that the appliances can be sampled for accelerant immediately at the fire scene by the investigator and there is no destruction done to the appliance itself. The appliance can then be examined by other experts for possible electrical malfunctions or tampering.

ACKNOWLEDGMENTS

My sincere thanks to Forensic Scientist Jerome Pihlaja from the Minnesota Bureau of Criminal Apprehension who conducted all testing and whose advice was invaluable.

Table 1. DFLEX* Card Test of Appliances for Accelerants (Test #1)

Appliance	Method of Heat	Accelerant Found	Proportional Area Under Peaks (Concentration)
Coffee Maker 1	Heater in Cabinet 118° - 130° F.	- 0 -	10
Coffee Maker 2	Warming Plate 170° F.	Front end diesel Trace of gas	20
Coffee Maker 3	Room Temperature 65° F.	Slight midrange gas Light end of diesel	5
Coffee Maker 4	Room Temperature 65° F. No accelerant	- 0 -	3
Television 1	Heater in Cabinet 118° - 130° F.	Trace of diesel	10
Television 2	Warming Plate 170° F.	- 0 -	5
Television 3	Room Temperature 65° F.	Front end of diesel Full range of gas	4
Television 4	Room Temperature Control/No accelerant	- 0 -	4

* A charcoal strip encased in a membrane and metal case that will absorb petroleum vapors.
NOTE - All appliances were burned with 125 ml of a 50/50 mix of diesel/gasoline for 15 minutes, except Television 4 and Coffee Maker 4 (which were burned with no accelerant). All appliances were doused heavily with water and after 24 hours, sealed in a bag with a DFLEX card for 48 hours.

Table 2. DFLEX* Card Test of Appliances for Accelerants (Test #2)				
Appliance	Method of Heating	Heating Time	Accelerant Found	Proportional Area Under Peaks (Concentration)
Coffee Maker 1	Room Temperature 65° F.	15 Hours	Alcohol/Gas No Diesel	74
Coffee Maker 2	Heating Pad 167° F.	15 Hours	Alcohol/Gas Trace of Diesel	33
Coffee Maker 3	Heater in Cabinet 125° F.	15 Hours	Alcohol/Gas No Diesel	39

* A charcoal strip encased in a membrane and metal case that will absorb petroleum vapors.
NOTE - Coffee makers had .05 ml of each of the following accelerants placed inside -- gasoline, diesel, and alcohol. These coffee makers were not burned, but rather were sealed inside a plastic bag with a DFLEX card for 15 hours. The DFLEX card was subsequently sent to the laboratory for analysis.

A Prototype for the Study of the Distribution and Characterization of Gasoline Over a Large Metropolitan Area

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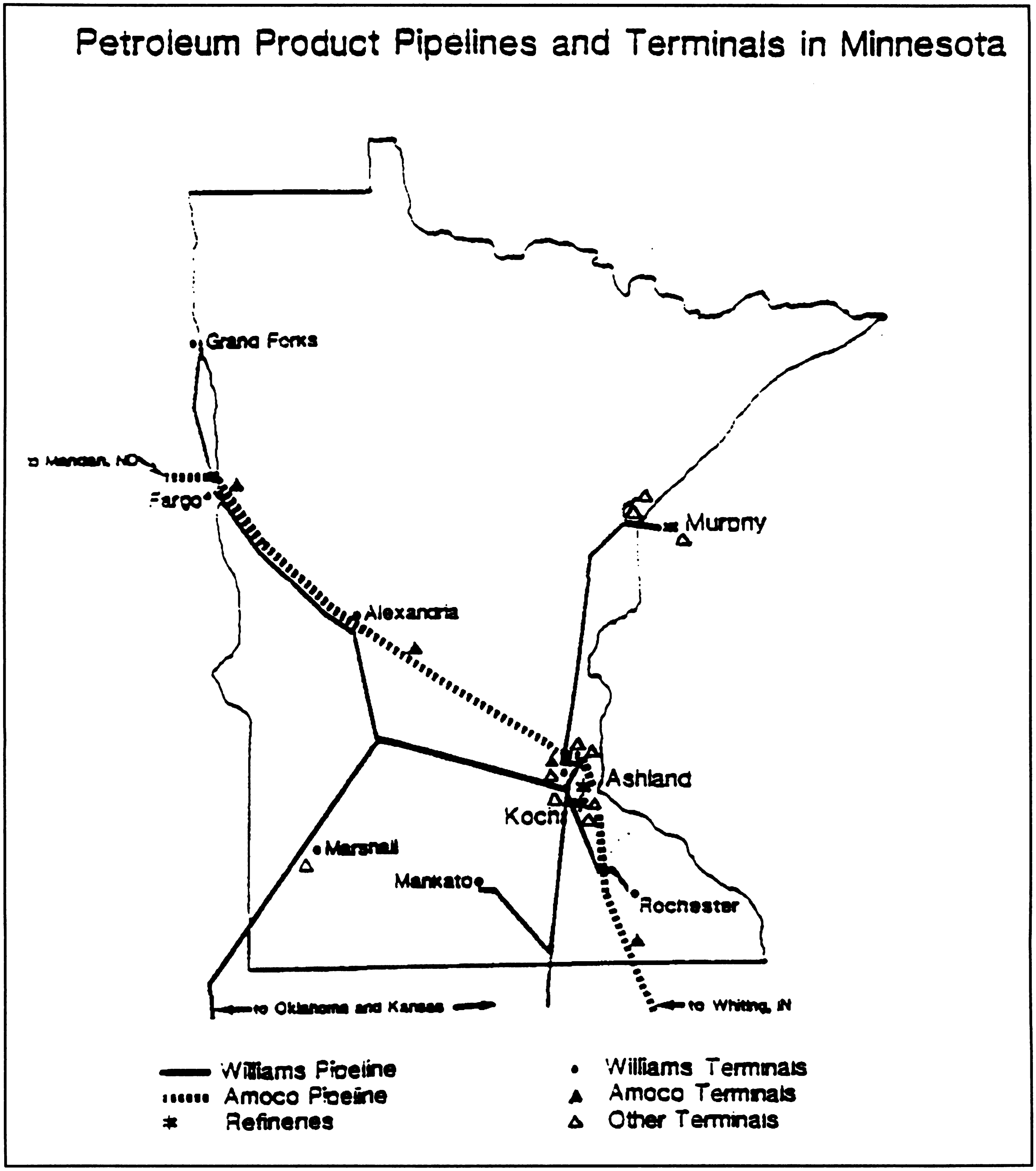
During the routine examination of samples containing gasoline, differences have been observed between submitted samples and laboratory references. The purpose of this study is to determine whether these differences are due to the source of the gasoline or to other factors not due to the manufacturer. A study of the distribution of gasoline in the metropolitan area of Minneapolis/St. Paul was designed so that student interns could complete a section of the study in the time allowed.

First, the state agencies that regulate the distribution were identified. Then, the terminal locations were identified and examples of distribution records were obtained. Figure 1 is a map of Minnesota showing the source of gasoline entering the state. Figure 2 is one page of a series of records indicating the transfer of gasoline shipments from one terminal to various retailers.

Samples of 87 octane gasoline samples were obtained from pipeline terminals, local refineries, and a river barge terminal. These samples were examined using the same gas chromatographic parameters used in the routine examination of suspected liquid accelerants and fire debris samples. The operating parameters are listed in Table 1. Overlaid chromatograms showing the variations between samples from different sources are shown in Figure 3. Samples of 87, 91, and 92 octane gasoline samples were obtained from one of the terminals and overlaid chromatograms showing the variations between samples of different octane ratings are shown in Figure 4. The range displayed is the region that contains the hydrocarbons eluting between pentane and the dimethyl naphthalenes.

Preliminary results of the samples tested indicate that the variation in samples from different original sources is insufficient to account for the observed differences described above. However, the greatest differences noted were in the range between pentane and the xylenes. Therefore, future studies will be designed to show the effect of different seasonal formulations, grade, weathering, and the age of samples using samples that have been reduced to more effectively display the hydrocarbons eluting after p-xylene.



Petroleum Product Pipelines and Terminals in Minnesota
Grand Forks
to Mandan, ND
Fargo
Murphy
Alexandria
Ashland
Koch
Marshall
Mankato
Rochester
to Oklahoma and Kansas
to Whiting, IN
Williams Pipeline
Amoco Pipeline
Refineries
Williams Terminals
Amoco Terminals
Other Terminals

Figure 1.

03/11/94 PETROLEUM BILLING TAX REPORT MINNESOTA FEBRUARY
ERICKSON NEWPORT TERMINAL REPORT

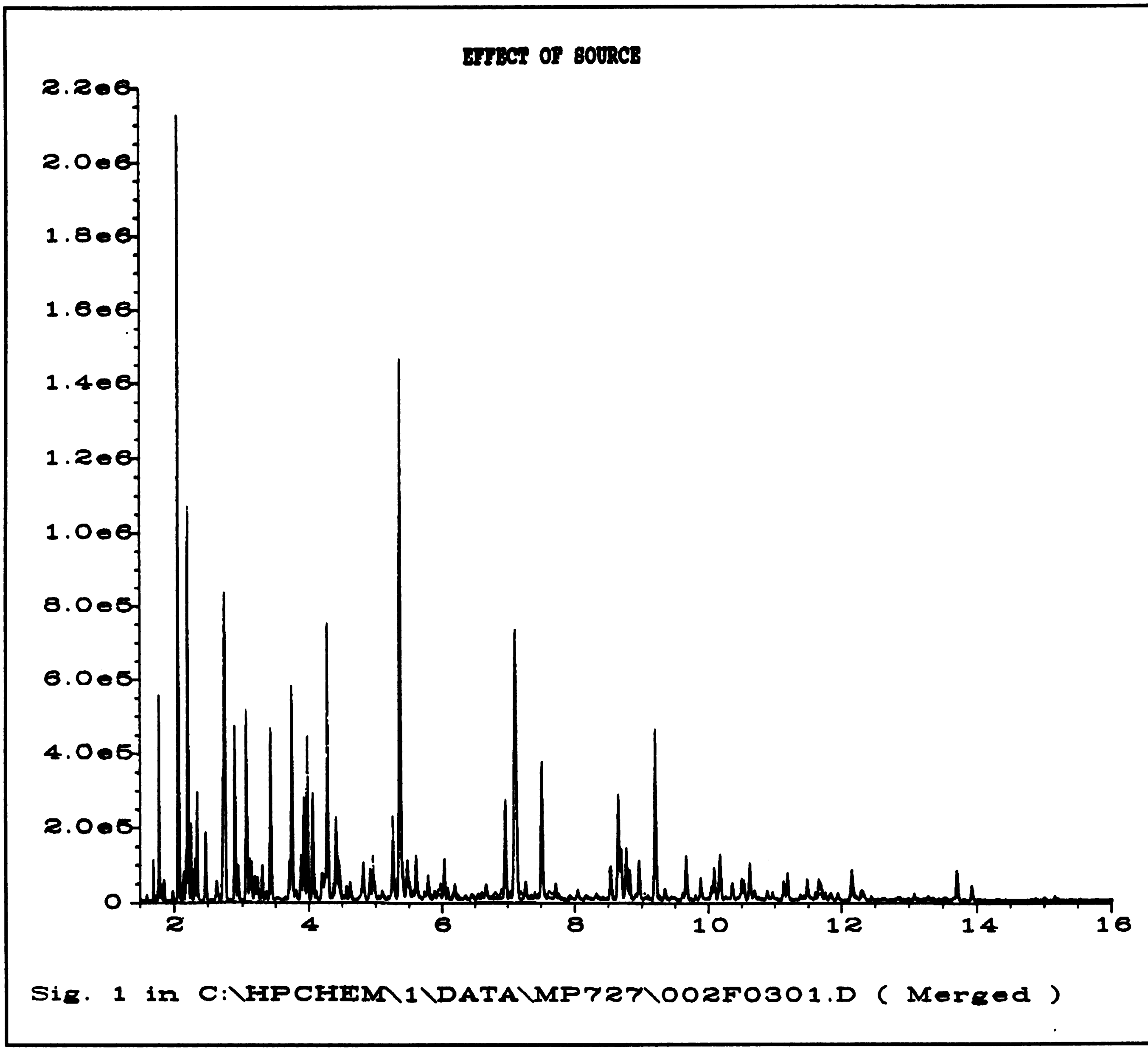
COMPANY- 1 ERICKSON PETROLEUM CORP.

HAULER	DATE	MANIFEST	STA	LOCATION	GAS	GASOHOL	DIESEL	ORIGIN
INDDIVTPT	02/01/94	0002910	213	BURNSVILLE MN	8003	802		ERICK NPT
INDDIVTPT	02/01/94	0002912	39	MINNETONKA MN	8517	853		ERICK NPT
INDDIVTPT	02/01/94	0002914	209	MPLS MN	8519	854		ERICK NPT
INDDIVTPT	02/01/94	*0002916	129	WAYZATA MN	8538	856		ERICK NPT
INDDIVTPT	02/01/94	*0002918	245	BLOOMINGTON MN	8607	860		ERICK NPT
INDDIVTPT	02/01/94	0002920	42	MPLS MN	8102	812		ERICK NPT
INDDIVTPT	02/01/94	0002922	253	FOREST LAKE MN	8517	852		ERICK NPT
INDDIVTPT	02/01/94	0002924	9	MPLS, MN	8510	853		ERICK NPT
INDDIVTPT	02/01/94	*0002926	139	PLYMOUTH MN	8616	863		ERICK NPT
INDDIVTPT	02/01/94	0002928	46	CAMBRIDGE MN	8536	858		ERICK NPT
INDDIVTPT	02/01/94	0002930	526	ROCKFORD MN	8102	814		ERICK NPT
INDDIVTPT	02/01/94	0002932	196	MONTICELLO MN	8511	854		ERICK NPT
INDDIVTPT	02/01/94	*0002934	548	PLYMOUTH MN	8145	828		ERICK NPT
INDDIVTPT	02/01/94	0002936	132	BIG LAKE MN	8514	630		ERICK NPT
INDDIVTPT	02/01/94	0002938	291	CHAMPLIN, MN	8616	864		ERICK NPT
INDDIVTPT	02/01/94	0002940	198	PRIOR LAKE MN	8107	813		ERICK NPT
INDDIVTPT	02/01/94	0002942	536	SAUK RAPIDS MN	8102	814		ERICK NPT
INDDIVTPT	02/01/94	0002944	243	CHAMPLIN MN	8510	854		ERICK NPT
INDDIVTPT	02/01/94	0002946	241	BROOKLYN PARK	8515	854		ERICK NPT
INDDIVTPT	02/01/94	0002948	214	DELANO MN	8105	812		ERICK NPT
INDDIVTPT	02/01/94	0002950	226	HINCKLEY MN	8501	490		ERICK NPT
INDDIVTPT	02/01/94	0002952	67	CHASKA MN	8520	855		ERICK NPT
INDDIVTPT	02/01/94	0002954	244	RAMSEY MN	8600	863		ERICK NPT
INDDIVTPT	02/01/94	0002956	186	MORA MN	8103	702		ERICK NPT
INDDIVTPT	02/01/94	0002958	258	PINE CITY MN	8097	110		ERICK NPT
INDDIVTPT	02/01/94	0002960	54	NORTH BRANCH MN	8519	855		ERICK NPT
INDDIVTPT	02/01/94	0002964	247	EAGAN MN	8516	854		ERICK NPT
INDDIVTPT	02/01/94	*0002966	548	PLYMOUTH MN	8507	853		ERICK NPT
INDDIVTPT	02/01/94	*0002968	129	WAYZATA MN	8527	857		ERICK NPT
INDDIVTPT	02/01/94	0002970	220	PLYMOUTH MN	8516	854		ERICK NPT
INDDIVTPT	02/01/94	0002972	238	BUFFALO MN	8106	813		ERICK NPT
INDDIVTPT	02/01/94	0002974	73	MPLS MN	8607	864		ERICK NPT
INDDIVTPT	02/01/94	0002976	233	LE SUEUR MN	8097	110		ERICK NPT
INDDIVTPT	02/01/94	0002978	223	HAM LAKE MN	8531	858		ERICK NPT
INDDIVTPT	02/01/94	0002980	83	SHAKOPEE MN	8520	855		ERICK NPT
INDDIVTPT	02/01/94	0002982	237	STILLWATER MN	8617	865		ERICK NPT
INDDIVTPT	02/01/94	0002984	4	ST PAUL MN	8512	855		ERICK NPT
INDDIVTPT	02/01/94	0002986	69	MPLS MN	8525	857		ERICK NPT
INDDIVTPT	02/01/94	*0002988	245	BLOOMINGTON MN	8519	852		ERICK NPT
INDDIVTPT	02/01/94	0002990	135	FARIBAULT MN	8348	270		ERICK NPT
INDDIVTPT	02/01/94	0002992	151	NEWPORT MN	8613	862		ERICK NPT
INDDIVTPT	02/01/94	0002994	2	MPLS MN	4512	454		ERICK NPT
INDDIVTPT	02/01/94	0002996	22	MPLS MN	4012	404		ERICK NPT
INDDIVTPT	02/01/94	0002998	199	CHANHASSEN MN	8533	855		ERICK NPT
INDDIVTPT	02/01/94	0003000	5	ST PAUL MN	8611	862		ERICK NPT
INDDIVTPT	02/01/94	0003002	236	FOREST LAKE MN	8515	853		ERICK NPT
INDDIVTPT	02/02/94	*0003004	139	PLYMOUTH MN	8616	860		ERICK NPT
INDDIVTPT	02/02/94	0003006	217	EDINA MN	8511	853		ERICK NPT
INDDIVTPT	02/02/94	0003008	15	OSSEO MN	4514	454		ERICK NPT
INDDIVTPT	02/02/94	0003010	145	BROOKLYN PARK M	4020	404		ERICK NPT

* - DENOTES MULTIPLE SHIPMENTS

Figure 2.

Table 1. Experimental Parameters		
Instrument	HP 5890	
Autosampler	HP 7673	
Data System	Vectra 486/20	
Column	HP - 5, 25m x 0.32mm x 1.05 ul	
Detector	FID	
Temperatures	Oven	60° C., hold 1 min. and program to 300° C. at 15°/min.
	Injector	250° C.
	Detector	310° C.
Flows	He	ca. 35 cm/sec.
	H_2	30 ml/min.
	Air	300 ml/min.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1.2e6
1.0e6
8.0e5
6.0e5
4.0e5
2.0e5
0
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8
10
12
14
16
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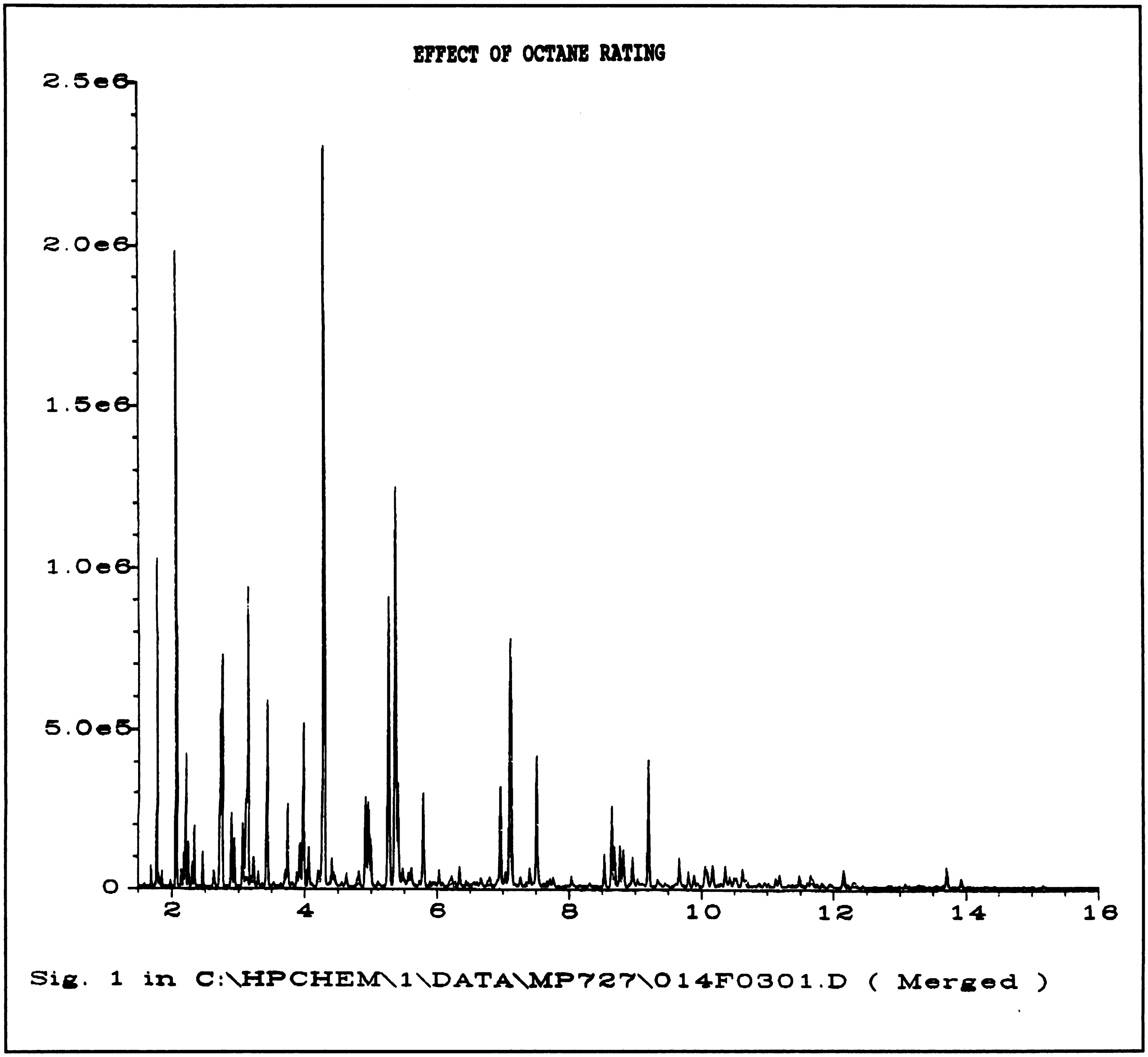
Figure 3.


EFFECT OF OCTANE RATING
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2.0e6
1.5e6
1.0e6
5.0e5
0
2
4
6
8
10
12
14
16
Sig. 1 in C:\HPCHEM\1\DATA\MP727\014F0301.D (Merged)

Figure 4.

Effect of Long-Term Storage of Arson Debris Evidence in the Form of Carbon Strip Samples

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The purpose of this experiment was to determine the effects of long-term room temperature storage on standards adsorbed onto carbon strips. This was be accomplished by allowing strips that have known standards adsorbed onto them to remain dry for measured periods of time, then re-eluting with pentane and reanalyzing the eluant using gas chromatography.

MATERIALS AND INSTRUMENTATION

Pentane: Fisher HPLC Grade, Fisher Scientific, Pittsburgh, PA

Cans: Davies Can Company, Solon, OH

Charcoal Strips: Pro-Tek Systems, Inc., Portland, CT

Tissue: Kimwipes EX-L Laboratory Wipers, Kimberly-Clark, Roswell, GA

Gas Chromatograph: Hewlett-Packard 5890 Series II, Wilmington, DE

Column: DB-1, 15 meter, 0.25 mm id, 1 um film thickness

Injector Temperature: 250°C

Detector Temperature: 300°C

Oven Temperature: 60°C initial to 300°C, ramped at 30°C/min

Time: Initial hold 1 minute, final hold 5 minutes

Carrier Gas: Helium, initial flow 4 ml/min, pressure held at 20 psi

Autosampler: 7673 GC/SFC injector, Hewlett-Packard, Wilmington, DE

PROCEDURE

Eleven commonly-encountered products containing petroleum distillates were selected for use as samples representing straight and branched alkanes, aromatics, and mixtures of alkanes and aromatics (see Table 1). Chromatograms were obtained by routine analysis of ignitable liquid residues placing one pipetted drop of sample onto a tissue placed inside a can of a type similar to those routinely used for collecting arson evidence. A charcoal strip was suspended from each can by means of a wire hanger and the can was sealed. The cans were heated for 2 hours at 60°C. The strips were then removed, placed into autosampler vials, and eluted with 0.80 ml pentane. A one-microliter sample of the elute was injected into the gas chromatograph using the autosampler.

Subsequent to instrumental analyses, the vials were decapped and the solvent was allowed to evaporate. After complete evaporation, the vials were recapped. These vials were then stored at room temperature in the laboratory.

In August after a storage period of 1 month, the samples were reanalyzed using routine gas chromatographic methods. The samples were quantitated at this time by measuring peak height. Again, the vials were decapped, the solvent allowed to evaporate, and the vials recapped and placed back

in storage. Reanalysis and requantitation were repeated in October, December, and March. Peak heights of major constituents were measured and normalized to the August data.

RESULTS

As expected, the apparent concentrations of the samples tended to decrease as a function of time, but remained chromatographically identifiable. The concentrations of the early eluting aromatic compounds as well as the alkanes appear to have declined more rapidly than that of the later eluting compounds. The paraffinic compounds tend to show a decrease in concentration greater than that of the aromatic compounds. Additionally, the pattern of evaporation of the studied compounds can be quite different than that seen as a result of controlled evaporation (weathering). Further study using duplicated samples and a longer period of time is warranted if more information is to be gathered.

CONCLUSION

Room temperature storage of carbon strips does not appear to hinder qualitative interpretation of chromatograms of ignitable liquid residues adsorbed onto carbon strips when stored for up to at least 8 months.

Table 1. Table of Standards

#2 Jet Fuels	PS Trading, Inc. Dallas, TX
#6 Naphthol Spirits 66/3	Unocal Chemical Division Petrochemical Group Los Angeles, CA
#10 Ultra Pure Lamp Oil	Lamplight Farms Menomonee Falls, WI
#12 Unleaded Gasoline	Texaco, Inc. Beacon, NY
#14 AL-50 Lacquer Thinner	Tem-Tex Solvents Corporation Temple, TX
#15 Servistar Paint Thinner	Parks Corporation Somerset, MA
#18 Gulf Lite Charcoal Starter	Reckitt & Colman Household Products Wayne, NJ
#20 Diesel No. 2	Texaco, Inc. Beacon, NY
#24 Coleman Fuel (Skellite)	Coleman Outdoor Products, Inc. Texaco Chemical Company Houston, TX
#35 Xylenes	Stephens Scientific Riverdale, NJ
#38 Gum Spirits Turpentine	W. M. Barr & Company, Inc. Memphis, TN

Library of Chromatographic Views of Charcoal Starters and Lamp Oils

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Texas Commission on Fire Protection
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In creating a standards reference library of products labeled charcoal starters and lamp oils, it has become apparent that there is a great diversity in the chemical composition of these products and how they will appear to the chemist who is analyzing fire debris in the arson laboratory. The chemist attempts to categorize the product in the final report which is returned to the submitting fire investigator. The investigator is then often faced with a bewildering description of a "range of alkanes" or "unclassified" product detected in fire debris, or seemingly inconsistent results from the laboratory when identifying charcoal starters from one case to the next. To assist the chemist and the investigator by pictorially demonstrating these product variations, a number of products bearing the name "charcoal starter" and "lamp oil" have been collected and analyzed using a gas chromatograph. Further studies were performed to illustrate the evaporative effects of fire and weather on these products.

Standards were analyzed using a gas chromatograph equipped with FID detector, capillary columns, and autosamplers using pentane as the solvent. Products were observed in three states: unevaporated, moderately evaporated (80%), and evaporated to dryness. The unevaporated and moderately evaporated samples were directly aliquoted into pentane; the residue sample was washed with pentane before analysis.

Initially, five milliliter (ml) aliquots were measured into disposable glass test tubes using graduated cylinders. Concurrently, a partial drop of each product was used to make the unevaporated solution in 1.6 ml of pentane. The rack of test tubes containing the products was left uncovered in a vent hood. In 4 days, very little evaporation had occurred, so the contents of each test tube was transferred into individual 20 ml beakers. A small fan was used to accelerate the evaporation process. As the initial 5 ml volume of the products evaporated to 1 ml or less, a solution was made in 1.6 ml of pentane. Again, a partial drop was used to make the 80% evaporated solution. When no more liquid was observed in the beaker, two pentane rinses of the residue were performed using a total of .8 ml of pentane to comprise the evaporated to dryness sample. The Ultra Lite All Purpose Fire Starter, which has the look and consistency of thick white paste, was diluted with pentane and filtered prior to analysis by gas chromatograph.

EQUIPMENT AND REAGENTS

Gas Chromatograph: Hewlett-Packard (HP) 5890 equipped with FID detector, and autosampler (HP 7673).

Capillary Column: J & W Scientific, DB-1, 15 meter, .25 millimeter internal diameter.

Pentane: OmniSolv HPLC grade.

The results of analysis demonstrated that unevaporated products sold as charcoal starter could be categorized as medium petroleum distillates, kerosenes, or unclassified. Unevaporated products labeled lamp oil could be categorized as alkanes (Exxon Norpars), medium petroleum distillates, or unclassified. Uniquely, Ultra Lite All Purpose Fire Starter contained ethanol.

Evaporation of some of the charcoal starters left a heavier product which could result in a change of classification. Evaporation to dryness also left negligible product in some instances, and peaks which could not be resolved by the column in others. With regard to brand names, Federated (Better Valu, Fine Fare) and Home Oil (Janet Lee, WalMart) charcoal starters were uniform in their product formulation; Royal Oak (HEB, TopCrest, Mega, Shurfine) and Gulf Lite (1986, 1992, 1995) were not. Little difference was noted between the two Crown products sold as lamp oil and charcoal starter.

In conclusion, it appears that the chemical composition of these products is very diverse, varying from brand to brand, and with new formulations within a brand. The label of charcoal starter or lamp oil appears to be inconsequential to the product classification. These differences underscore the importance of testing a comparison product obtained from the fire scene whenever available. The mild room temperature evaporation study illustrates evaporative effects which fire and weather would rapidly increase, emphasizing the urgency of rapid collection and proper preservation of forensic arson evidence.

Table 1. Product Classification and Time Required to Achieve 80% Evaporation and Evaporation to Dryness of 5 ml Volume.						
Product		Initial Class (Unevaporated)	* Days to > 80% Evaporation	Class at > 80% Evaporation	Days to Evaporate to Dryness	Class at Dryness
#10	Lamplight Farms Ultra Pure Lamp Oil	Alkanes: C12 - 14	*(60% evap)* (4) + 23	Alkanes: C13 - 15	Not Available	Not Available
#91	Crown Lamp Oil	Unclassified	(4) + 9	Unclassified	(4) + 14	Unclassified
#92	Lamplight Farms Lamp Oil	MPD	(4) + 7	MPD	(4) + 11	Unresolved
#18	Gulf Lite (1992) Charcoal Starter	Unclassified/ Kerosene	(4) + 7	Kerosene	(4) + 21	Alkanes: C15 - 16
#25	Royal Oak Lighter Fluid/Charcoal Starter	Unclassified	1	Unclassified	(4) + 2	Unresolved (Negligible)
#54	Gulf Lite (1986) Charcoal Starter	Unclassified	(4) + 4	Unclassified	(4) + 7	Unresolved
#59	Janet Lee Charcoal Lighter Fluid	MPD	(4) + 4	MPD	(4) + 7	Heavy Alkanes
#81	Better Valu Charcoal Lighter Fluid	Kerosene	(4) + 11	Kerosene	(4) + 21	Heavy Alkanes
#82	Klean-Strip Charcoal Lighter	Unclassified	(4) + 8	Unclassified	(4) + 11	Heavy Alkanes (Negligible)
#83	Top Crest Charcoal Lighter Fluid	MPD	(4) + 4	MPD	(4) + 7	Heavy Alkanes
#84	Mega Charcoal Lighter Fluid	Kerosene	(4) + 11	Kerosene	(4) + 21	Heavy Alkanes
#85	Shurfine Charcoal Lighter Fluid	Kerosene	(4) + 11	Kerosene	(4) + 21	Heavy Alkanes
#86	Fine Fare Charcoal Starter	Kerosene	(4) + 11	Kerosene	(4) + 21	Heavy Alkanes
#88	Ultra Lite All-Purpose Fire Starter	Ethanol	XXX	XXX	XXX	XXX
#89	Crown Charcoal Starter	Unclassified	(4) + 9	Unclassified	(4) + 14	Unresolved
#90	WalMart Charcoal Starter	MPD	(4) + 4	MPD	(4) + 7	Heavy Alkanes
#93	Gulf Lite (1995) Charcoal Starter	MPD	2	MPD	5	Heavy Alkanes

* - (4) days initially in test tubes before transferred into beakers.
XXX - No results (only a pentane extract was performed on this product which has the look and consistency of thick white paste).

Table 2.		
Lamp Oils		
#10	Lamplight Farms Ultra-Pure Lamp Oil	Lamplight Farms Menomonee Falls, WI
#91	Crown Scented Lamp Oil Ultra Refined	Packaging Service Co., Inc. Pearland, TX
#92	Lamplight Farms Lamp Oil	Lamplight Farms Menomonee Falls, WI
Charcoal Starters		
#18	Gulf Lite Mesquite Scented Charcoal Starter	Reckitt & Colman Household Products Wayne, NJ
#25	Royal Oak Lighter Fluid/ Charcoal Starter	Royal Oak Enterprises, Inc. Atlanta, GA
	H. E. B. Lighter Fluid/ Charcoal Starter	H. E. Butt Grocery Company San Antonio, TX
#54	Gulf Lite Odorless Charcoal Starter (Prior to 1986)	
#59	Janet Lee Charcoal Lighter Fluid	Home Oil Company, Inc. Wichita, KS (Distributed by Albertson's Inc. Boise, ID)
#81	Better Valu Charcoal Lighter Fluid	Union Oil Company of California Schaumburg, IL (Packaged for Federated Foods Arlington Heights, IL)
#82	Klean-Strip Clear Charcoal Lighter	W. M. Barr & Company, Inc. Memphis, TN
#83	TopCrest Odorless Charcoal Lighter Fluid	Royal Oak Enterprises, Inc. Atlanta, GA (Distributed by Topco Associates Skokie, IL)
#84	Mega Charcoal Lighter Fluid	Royal Oak Enterprises, Inc. Atlanta, GA (Distributed by Topco Associates Skokie, IL)
#85	Shurfine Charcoal Lighter Fluid	Royal Oak Enterprises, Inc. Atlanta, GA
#86	Fine Fair Charcoal Starter	(Distributed by Federated Foods Arlington Heights, IL) (Also distribute Red and White, Parade, and High Top Charcoal Starters)
#88	Ultra Lite All-Purpose Fire Starter	Classic Fuels, Inc. Fort Collins, CO
#89	Crown Charcoal Starter - Odorless, Clear	Packaging Service Co., Inc. Pearland, TX
#90	WalMart Barbeque Charcoal Starter	Home Oil Company, Inc. Wichita, KS
#93	Gulf Lite Charcoal Starter (1995)	Reckitt & Colman Household Products Wayne, NJ

Application of a Method for Extraction and Analysis of Alcohols and Acetone in a Case Involving Serial Arson/ Homicide

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In late 1993 a series of arsons where the victim was discovered to have been beaten, raped, and murdered occurred in central Florida. In the first three cases, the fire was quite extensive. The evidence collected and submitted failed to reveal any ignitable liquid. It was theorized that the perpetrator used material at the scene to set the fire. A fourth arson/homicide occurred; physical conditions within the scene did not allow the fire to progress substantially. Evidence was collected and submitted to the laboratory. Bottles of rubbing alcohol were found at the scene and were theorized as being the accelerant.

A method for determining low molecular weight alcohols and acetone using passive headspace concentration was being developed for publication (Phelps *et al.* 1994). The method was applied to the case samples.

MATERIALS AND METHODS

Separation Technique - The method for recovery of volatile materials is based on ASTM E-1413-92, passive headspace concentration onto a carbon strip. Elution from the strip is with carbon disulfide. Carbon strips were prepared from charcoal membranes purchased from Pro-Tek Systems, Inc. The carbon disulfide was certified spectral analyzed from Fisher Scientific.

Gas Chromatography - Analyses were performed on a Perkin-Elmer 900 Autosystem with flame ionization detector (GC/FID) followed by ion trap detection (GC/ITD). Data were acquired with both PENelson's Turbochrom 4 and Finnigan MAT's ITDS4.1 software. Operating parameters are listed in Tables 1 and 2.

The method cited cautions that low molecular weight alcohols and/or acetone may be produced as a pyrolysis product. The method for separation requires only one preparation step for determination of low molecular weight components as well as heavier ignitable liquids. GC/FID is used to screen for ignitable liquids and GC/ITD is utilized for confirmation.

RESULTS

GC/FID revealed components with retention times the same as for isopropyl alcohol on all submitted samples. No other ignitable liquids were indicated. All samples were then analyzed by GC/ITD. Isopropyl alcohol was confirmed by both mass spectra and retention time. The isopropyl alcohol found was at varying levels on each of the samples tested (Table 3).

The original samples included a comparison sample which was pyrolyzed prior to testing. Another comparison sample was obtained from the scene at a later date. This sample was split with half tested without burning and the other half tested after burning. Isopropyl alcohol was found on the unburned matrix. No alcohol was found on the burned matrix. These factors indicated that samples with similar quantities of isopropyl alcohol should not be reported as positive. Three samples contained isopropyl alcohol at levels 7 to 12 times greater than those in either of the comparison samples (Figure 1). Isopropyl alcohol was positively reported on those three samples.

CONCLUSIONS

When attempting to identify low molecular weight alcohols or acetone a lower limit for detection should be set. Published information indicates that alcohols and/or acetone may be produced as pyrolysis products (Phelps *et al.* 1984). The second comparison sample indicates that the isopropyl alcohol found in all samples was not produced from pyrolysis. Prudence, however, dictated that only those samples with substantially greater quantities of isopropyl alcohol should be reported.

The finding of alcohol was consistent with the modus operandi of the perpetrator. He would initiate the fire using available material including the rubbing alcohol commonly found in medicine chests. This was the last fire to occur before a suspect was arrested. He was tried for two of the homicides and was found guilty in both. In each trial, he was sentenced to death. While in prison awaiting appeal of sentence, he was stabbed by other prisoners and died.

REFERENCES

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Phelps, J. L., Chasteen, C. E., and Render, M. M. Extraction and analysis of low molecular weight alcohols and acetone from fire debris using passive headspace concentration. *Journal of Forensic Sciences* (January 1994) 39(1):194-206.

Table 1. GC/FID Parameters.

Column	SGE, 0.32 mm x 25 M, 0.5 uM methyl silicone bonded phase	
Carrier Gas	Helium, 42 cm/s linear velocity at 50°C	
Injector	300°C, split mode, 30:1 split ratio, 2 uL injection	
Detector	300°C	
Temperatures	Initial	50°C
	Hold 1	1 minute
	Ramp Rate	20°C/minute
	Final	300°C
	Hold 2	2 minutes

Table 2. GC/ITD Parameters for Alcohol Identification		
Column	SGE, 0.32 mm x 50 M, 0.5 uM methyl silicone bonded phase	
Carrier Gas	Helium, 19 cm/s linear velocity at 35°C	
Injector	200°C, split mode, 30:1 split ratio, 2 uL injection	
Detector	200°C	
Transfer Line	200°C	
Temperatures	Initial	35°C
	Hold 1	6 minutes
	Ramp Rate	30°C/minute
	Final	300°C
Mass Spectrometer	Scan Range	30 amu - 70 amu
	Scan Cycle	0.1 second/scan
	Start Time	0.0 minute

Table 3. Relative Intensities of Isopropyl Alcohol Identified Peaks	
Sample	Peak at 100%
1	215696
2	200405
3	5395
4	4625
5	48616
6	3304
7	4750

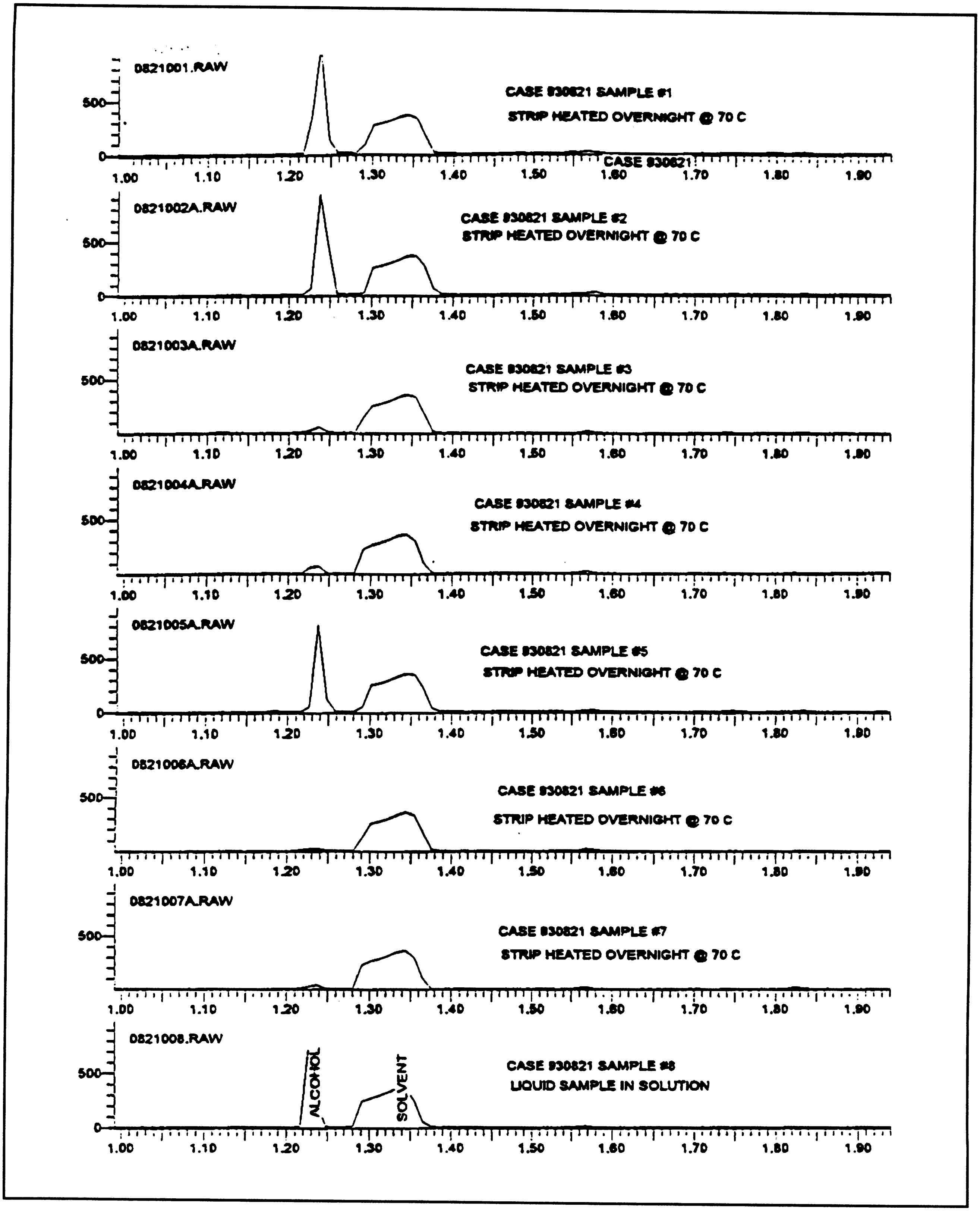

Figure 1. Comparisons of RT and peak size (area and height) of seven case samples with case standard of Isopropyl Alcohol.

Preparation of Pyrolysis Standards to Approximate Pyrolysis Products Observed in Fire Scenes

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Ignitable liquids are identified by recognition of chromatographic patterns, reconstructed ion profiles, and target compound identification (ASTM E-1387-90 & EGCMS-94). These methods may be interfered with by pyrolysis products from materials inherent to the scene. Pyrolysis products contain many of the organic chemicals present in ignitable liquids (DeHaan and Bonarius 1988; Lowry *et al.* 1985; Lowry *et al.* 1985). This may result in coelution with components of ignitable liquids. Comparison samples of the matrix may be submitted for analysis (ASTM E-1387-90 and NFPA 921 9-2). Often the matrix selected is unburned. Building materials may also be purchased to construct a library of standards.

To make effective comparisons it is necessary to pyrolyse the comparison samples. Different methods of burning the same matrix will result in variations to the composition of pyrolysis products (DeHaan and Bonarius 1988; Yinon and Smith 1987). Comparisons of fire debris unknowns against pyrolysis standards were performed. These show that modified destructive distillation produces pyrolysis which most closely approximates pyrolysis occurring in fire scenes.

MATERIALS AND METHODS

Separation Technique - The method for recovery of volatile materials from fire debris is based on ASTM E-1413-92, passive headspace concentration onto a carbon strip. Elution is with carbon disulfide. Carbon strips were prepared from charcoal membranes purchased from Pro-Tek Systems, Inc. The carbon disulfide was certified spectral analyzed from Fisher Scientific.

Gas Chromatography - Analyses were performed on a Perkin-Elmer 900 Autosystem with either flame ionization detector (GC/FID) or ion trap detector (GC/ITD). Data were acquired with either PENelson's Turbochrom 4 or Finnigan MAT's ITDS4.1. Operating parameters are listed in Tables 1 and 2.

Standards - Standard building materials were purchased from Lowe's Building Supply or Walmart.

Methods for Preparing Pyrolysis Library Samples - The matrix sample was cut into four equal pieces. Each was placed in a clean unused gallon can. Each can was subjected to one of the four following methods. Extinguishment was by suffocation.

Method 1 - The sample was not burned. The only heating occurred during the separation technique.

Method 2 - The sample was removed from the can and burned in the open with a propane torch until the surface was charred.

Method 3 - The can lid was pierced five times then returned to the can. The can was placed on a ring stand and the bottom heated with a propane torch. Heating continued until smoke had evolved from the holes in the lid for 2 minutes. After heating, the can was allowed to cool for 2 minutes. The pierced lid was replaced by a new lid.

Method 4 - The can lid was pierced five times then returned to the can. The can was placed on a ring stand and the bottom heated with a propane torch. Heating continued until smoke had evolved from the holes in the lid for 4 minutes. After heating, the can was allowed to cool for 2 minutes. The pierced lid was replaced by a new lid.

RESULTS

A library of pyrolysis products prepared under each method was assembled. This included both the GC/FID and GC/ITD patterns. GC/ITD revealed that some matrices produce profiles and target compounds similar to those in ignitable liquids. When inconclusive patterns were obtained from actual case files, they were compared to the library. The pattern of components from actual fire debris most often approximated the patterns from similar matrices prepared by Method 3 (Figure 1).

CONCLUSIONS

Unburned comparison samples from a case are routinely burned according to Method 3. If the comparison sample shows GC/FID ro GC/ITD patterns matching those from the unknowns, then the unknown must be deemed as negative. In cases where no comparison sample was submitted, the pyrolysis library matrix prepared by Method 3 provided an alternative. As each fire scene is unique, this method cannot duplicate all pyrolysis products obtained from fire debris in all samples. Case samples should be inspected to determine the degree of burning prior to choosing a pyrolysis method. Method 3 is not appropriate for samples with either minimal surface burn or advanced carbonization.

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Table 1. GC/FID Parameters.		
Column	SGE, 0.32 mm x 25 M, 0.5 uM methyl silicone bonded phase	
Carrier Gas	Helium, 42 cm/s linear velocity at 50°C	
Injector	300°C, split mode, 30:1 split ratio, 2 uL injection	
Detector	300°C	
Temperatures	Initial	50°C
	Hold 1	1 minute
	Ramp Rate	20°C/minute
	Final	300°C
	Hold 2	2 minutes

Table 2. GC/ITD Parameters		
Column	SGE, 0.32 mm x 50 M, 0.5 uM methyl silicone bonded phase	
Carrier Gas	Helium, 2 mL per minute, 23 psi at 70°C	
Injector	260°C, split mode, 30:1 split ratio, 2 uL injection	
Transfer Line	250°C	
Temperatures	Initial	70°C
	Hold 1	0 minute
	Ramp Rate 1	2°C/minute
	Temp. 2	130° C
	Hold 2	0.2 minutes
	Ramp Rate 2	10°C/minute
	Final Temp.	260°C
	Hold 3	10.8 minutes
Mass Spectrometer	Scan Range	50 amu - 300 amu
	Scan Cycle	1.0 second/scan
	Start Time	5.0 minutes

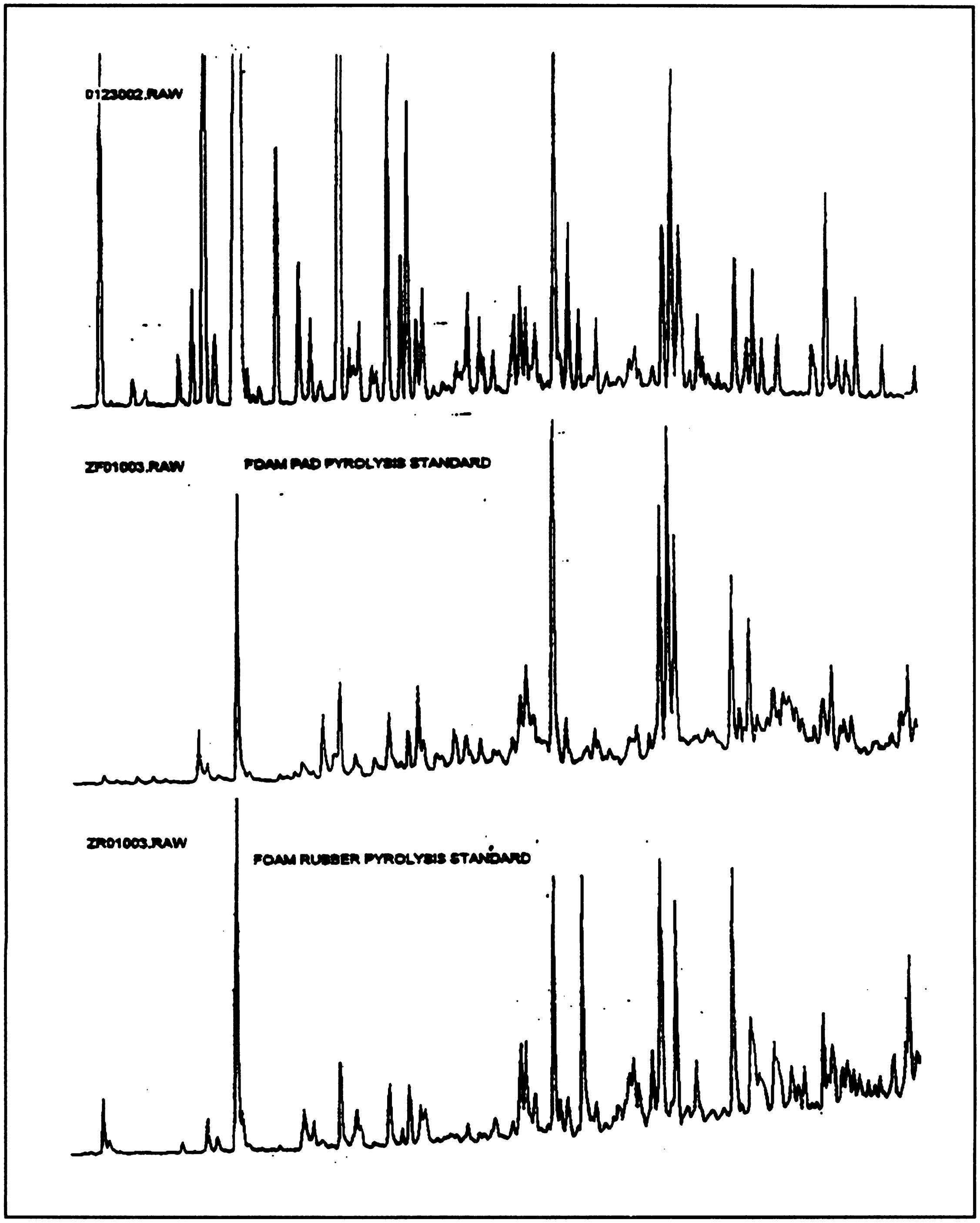

Figure 1. Comparison of a case sample with two similar matrices prepared by Method 3.

The Recognition of Class A Firefighting Foams During Gas Chromatographic Analysis of Fire Debris

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Traditionally Class A firefighting foams have been used for wildland fires, but some fire departments are beginning to utilize Class A foams on structure fires as well. Class A foams can significantly reduce the amount of water required during fire suppression which is an important concern where water supplies are limited or in locations where water must be hauled to the fire scene. Class A firefighting foam concentrates are added to water in concentrations of 0.1% - 1.0% to reduce the surface tension of water. Because the composition of foam concentrates includes some flammable and/or combustible liquids, Class A foam concentrates may be detected when examining fire debris samples for possible accelerants by gas chromatography (GC).

MATERIALS AND METHODS

Twenty-five-ml samples of Forexpan S 0.1% - 1% (Angus Fire, Angier, NC), SILV-EX (Ansul Fire Protection, Marinette, WI), Fire-Trol Firefoam 103B (Chemonics Industries, Orland, CA), and Phos-Chek WD881 (Monsanto Company, St. Louis, MO) foam concentrates were collected and placed in unused metal quart cans. Material Safety Data Sheets for each of the foam concentrates were also obtained. The four brands of Class A foam concentrates were sampled with cold headspace, heated headspace, and passive adsorption elution techniques employed with GC analysis of fire debris samples. The headspace samples were injected on a 20-foot 3% SP-2100 packed column (Supelco, Inc., Bellefonte, PA) with an initial temperature of 50°C for 4 minutes, ramp of 8°C per minute to 180°C for 4 minutes. The adsorption elution runs (Figure 1) were made on a 15-meter DB-1 column (J & W Scientific, Folsom, CA) with an initial temperature of 50°C for 2 minutes, ramp of 25°C per minute to 250°C for 4 minutes with carbon disulfide as the eluant. Both columns were connected to the flame ionization detectors.

RESULTS AND DISCUSSION

All four of the foam concentrates are multicomponent proprietary mixtures with similar compositions. Although volatile primary alcohols were detected by the cold and heated headspace techniques, their recovery in fire debris samples may be improbable. The heavier, less volatile components (including diethylene glycol monobutyl ether and hexylene glycol) were detected by passive adsorption elution methods and have been detected in actual casework.

Class A foams do not conform to one of the standard classifications of the ASTM Standard E-1387-90 classification scheme, but could be placed in the unclassified group. The detection of alcohols and accompanying later eluting components will help indicate the source may be from a Class A foam and prevent the misidentification as an alcohol accelerant or a light petroleum distillate. The chromatograms produced from each of the four Class A foam

concentrate samples lack the bell-shaped curve characteristic of medium petroleum distillates and the regularly-spaced series of consecutive n-alkane peaks characteristic of kerosene or heavy petroleum distillates. The characteristic gasoline components are not present in Class A foams.

Although it seems unlikely that Class A foam concentrates would be used as an accelerant, being aware of their possible presence and composition will allow laboratory personnel to carefully consider the detection of their components in fire debris samples.

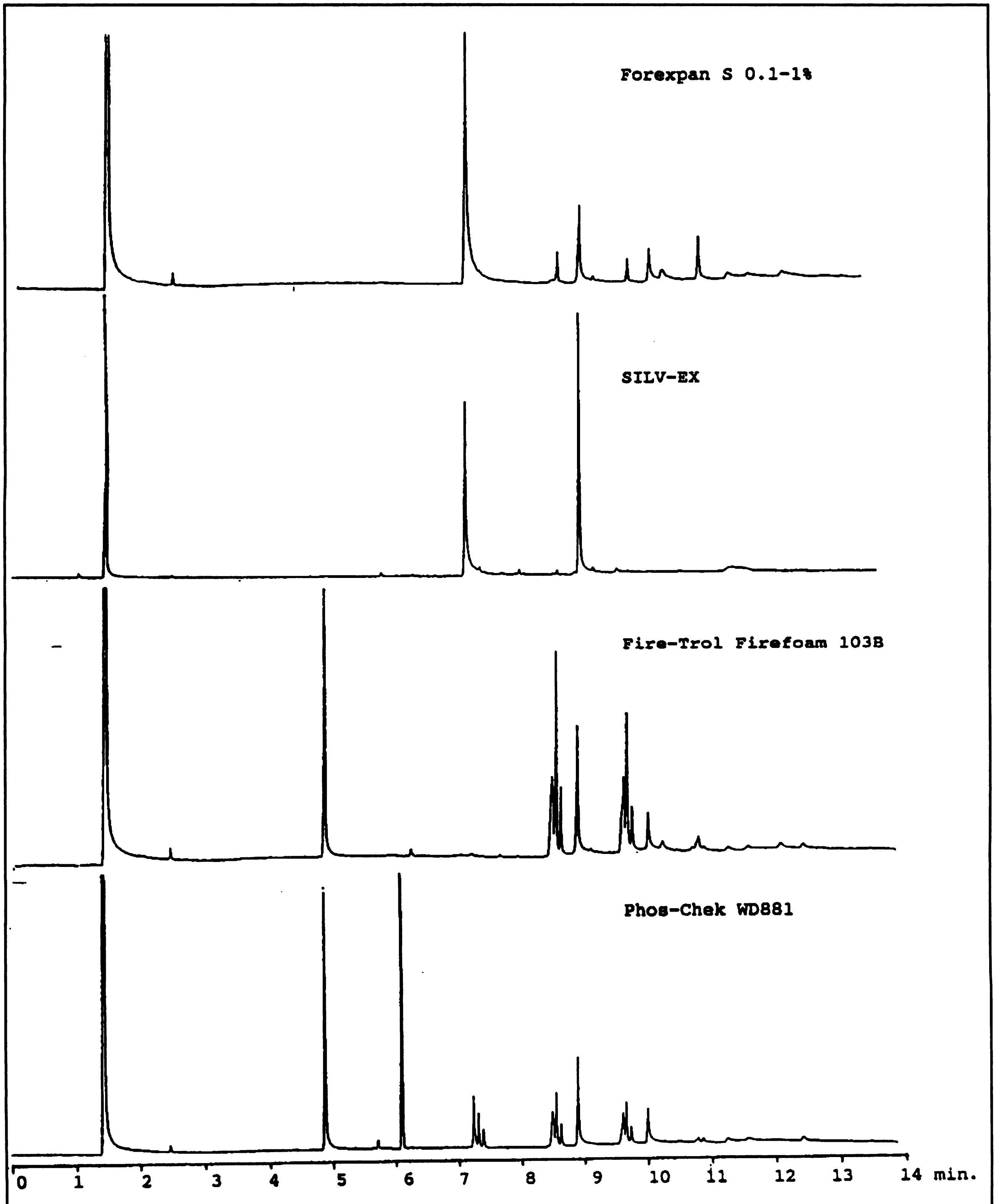

Figure 1. Chromatograms of four Class A fire foam concentrates.

A Fast and Simple Method for the Analysis of Accelerants From Fire Debris Using Headspace Solid-Phase Microextraction

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Solid-phase microextraction (SPME) is a fast, simple, and sensitive technique which does not require the use of solvents and is readily automated (Arthur *et al.* 1992). SPME involves the extraction of organic compounds from aqueous or gaseous samples into sorbent-coated silica fibers which can be transferred directly to the injector of a gas chromatograph (GC). SPME has primarily been applied to the analysis of environmentally important organic contaminants, either directly from water or from the headspace above aqueous solutions (Shirley 1994; Zhang and Pawliszyn 1993).

Established methods for sampling flammable or combustible liquid residues from fire debris samples include: screening methods such as static headspace sampling which is capable of detecting ca. 10 µl of petroleum product (ASTM E-1388-90) and concentration methods, including solvent extraction (ASTM E-1386-90), dynamic headspace (ASTM E-1413-91), and passive headspace (ASTM E-1387-90) concentration which are capable of detecting ca. 0.1 µl of liquid residues. The concentration methods all involve the desorption of residues with a volatile solvent, typically carbon disulfide, followed by analysis by GC (ASTM E-1387-90).

The goals of the present study were to develop a simple, rapid, solventless concentration method with sensitivity comparable or better than the conventional concentration methods. Presently, we report a comparison of the developed SPME method to the activated charcoal strip (ACS) passive headspace concentration method (ASTM E-1387-90).

MATERIALS AND METHODS

Standard fixed volumes of Fina 87 octane gasoline and other accelerants such as diesel fuel and paint thinner, were spiked on Kimwipes (Kimberly-Clark, Roswell, GA), and placed into aluminum quart cans (American International, Miami, FL) and analyzed by the two methods described below. Accelerant spiked samples of burned pine and plastic were also analyzed to determine the utility of the SPME method in the presence of pyrolysis products.

ACS PROCEDURE

ASTM E-1387-90 using the GC parameters described in Table 1.

SPME PROCEDURE

The can containing the accelerant standard on a Kimwipe was sealed with a lid having a 6 mm septum (Fisher Scientific) and heated in an oven to 60°C for 30 minutes. The can was removed from the oven and a 100 µm film thickness polydimethylsiloxane-coated fiber which was previously retracted into the needle of the SPME holder (Supelco, Bellefonte, PA) was inserted into the can through the septum (Figure 1). The plunger was then depressed, exposing the fiber to the headspace for ca. 20 minutes. The fiber was then retracted into the SPME needle and the assembly was removed from the can. The needle was inserted directly into the injection port of the Perkin-Elmer 8420 GC (Norwalk, CT), and the plunger was depressed for 10 seconds to desorb the analytes (Table 2) into the GC column (HP-1, Hewlett-Packard) by splitless injection (Table 1). The resulting chromatograms from the comparison of the ACS v. SPME techniques are shown in Figures 2 through 5.

CONCLUSIONS

The headspace SPME technique described here has been found to be more sensitive than the passive headspace concentration technique, yet is simpler, faster, less expensive, and does not require the use of any solvents. Optimization of the injection parameters, including cryogenic focusing, and other variables, including the SPME fiber film thickness and type as well as the extraction temperature are currently being investigated in an attempt to further improve the sensitivity of this method.

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Zhang, Z. and Pawliszyn, J. Headspace solid-phase microextraction. *Analytical Chemistry* (July 1993) 65(14):1843-1852.

TABLE 1—Gas *chromatographic conditions used in this study.*	
Injection Port Temperature	220 °C
Oven Program	Initial 35 °C, 2 min., $Ramp_1$ 10 °C/min. to 220 °C, hold 2 min., $Ramp_2$ 30 °C/min. to 300 °C, 5.0 min.
Detector Temperature	300 °C
Splitless Mode (SPME), (ACS injections were Split.)	Split was turned on 6 sec. after injection and holder was removed from the injection port 4 sec. later.
Gas Flows	1 ml/min, 50:1 split ratio
Injection Port Sleeve Size (SPME)	Low Volume, (2 mm)

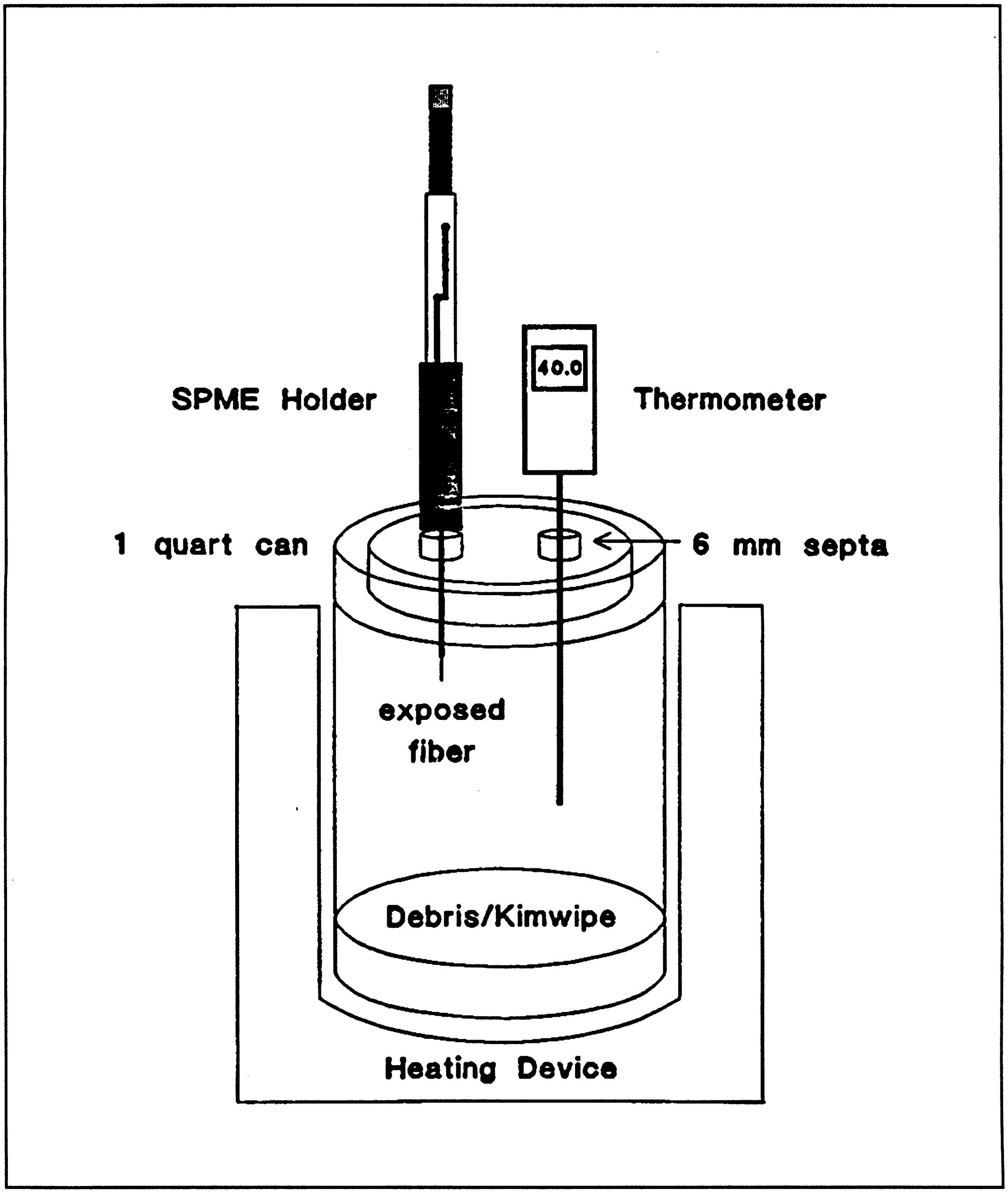


Figure 1. Schematic diagram of the experimental setup for the SPME apparatus.

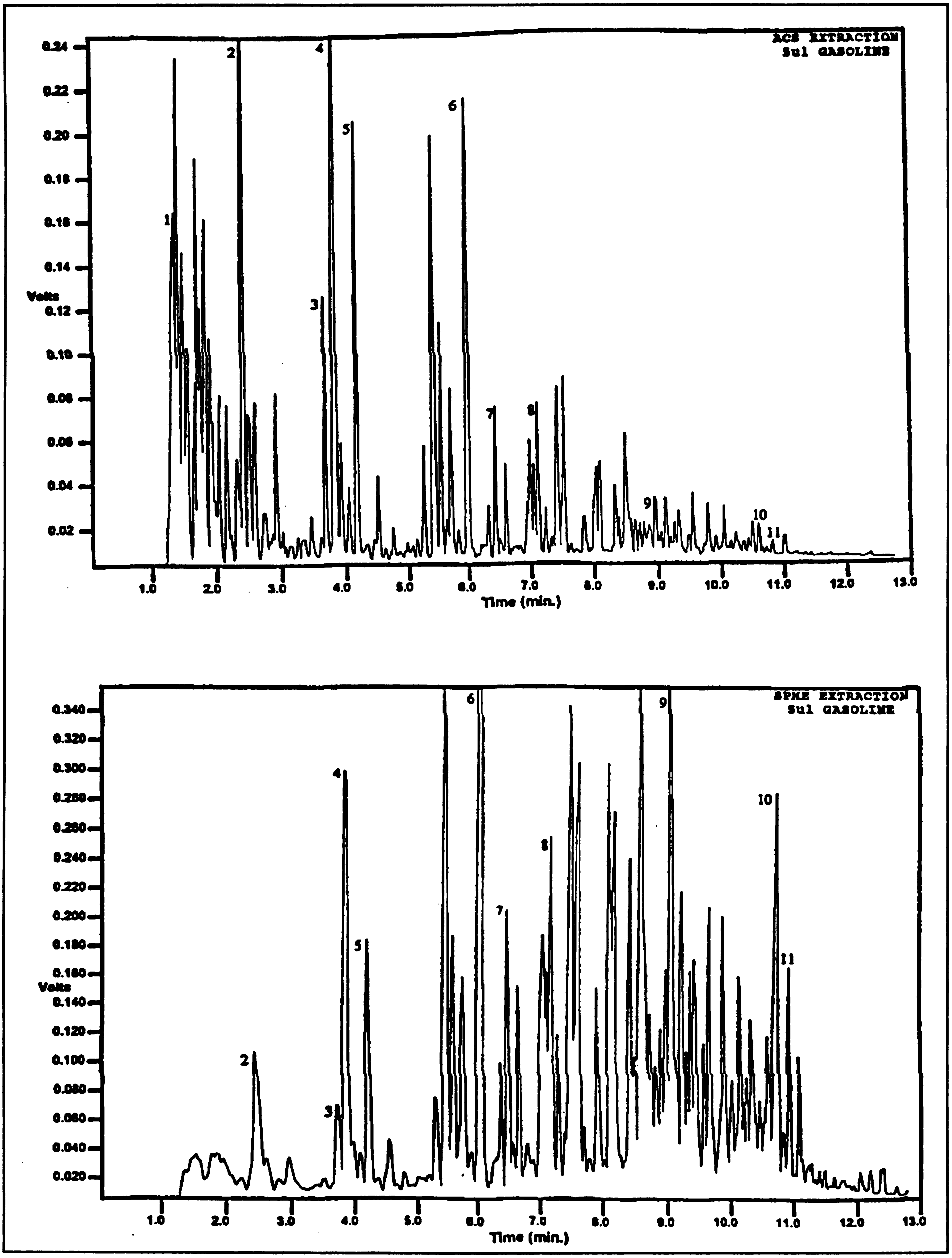


Figure 2. Chromatogram of the ACS extraction (top) and SPME extraction (bottom) of a can spiked with 5 μl of gasoline (peak identity in Table 2).

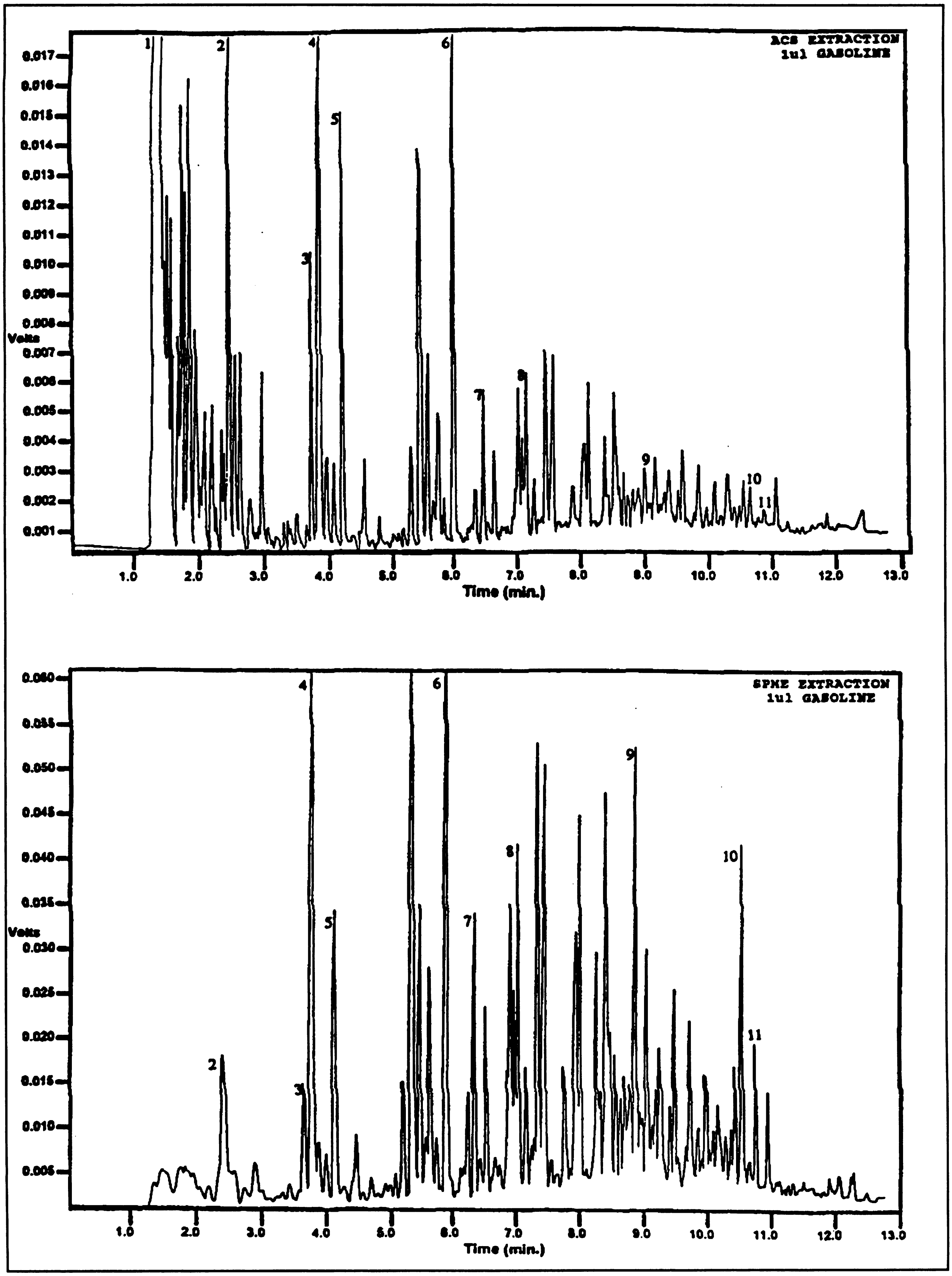


Figure 3. Chromatogram of the ACS extraction (top) and SPME extraction (bottom) of a can spiked with 1 uL of gasoline (peak identity in Table 2).

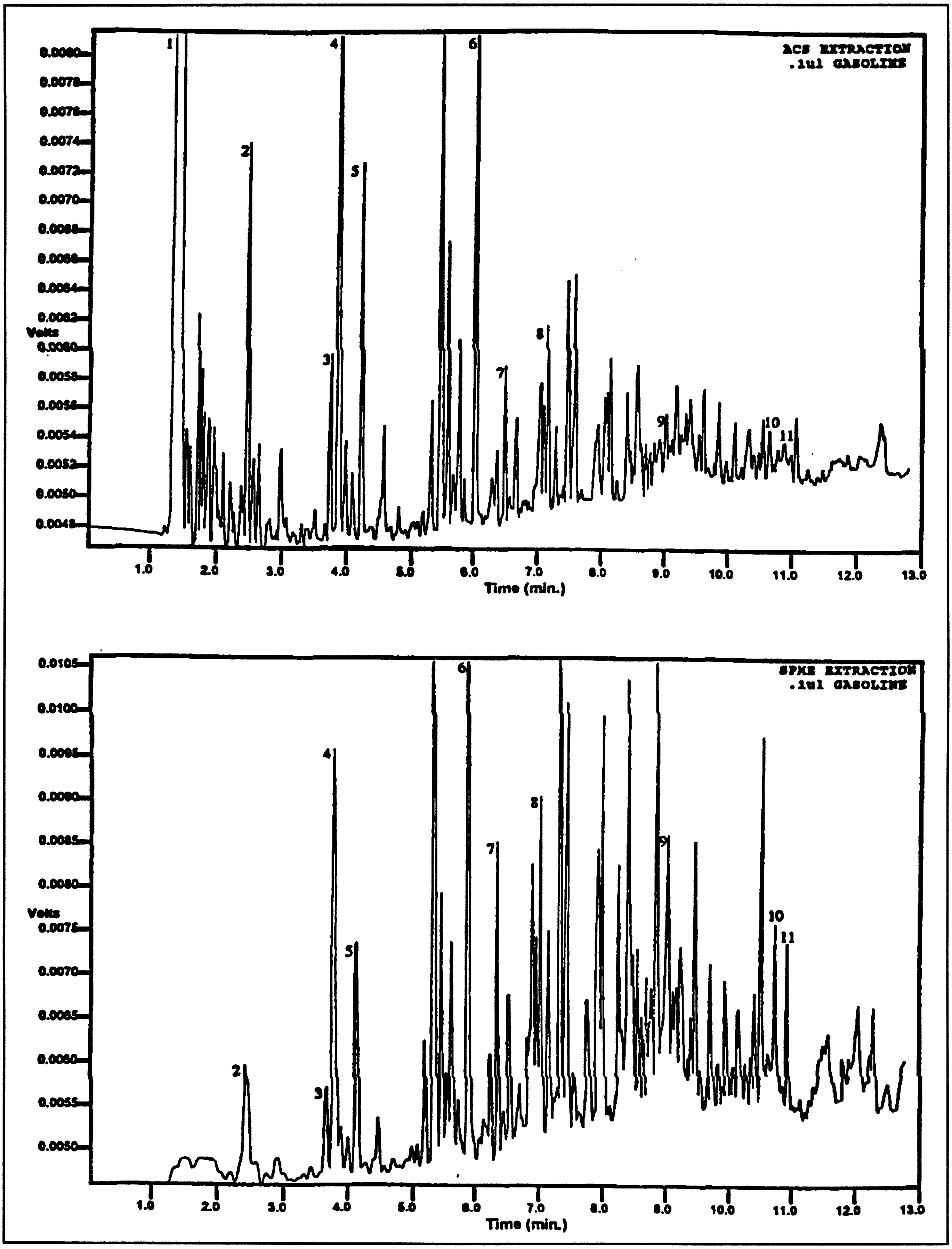


Figure 4. Chromatogram of the ACS extraction (top) and SPME extraction (bottom) of a can spiked with 0.1 uL of gasoline (peak identity in Table 2.)

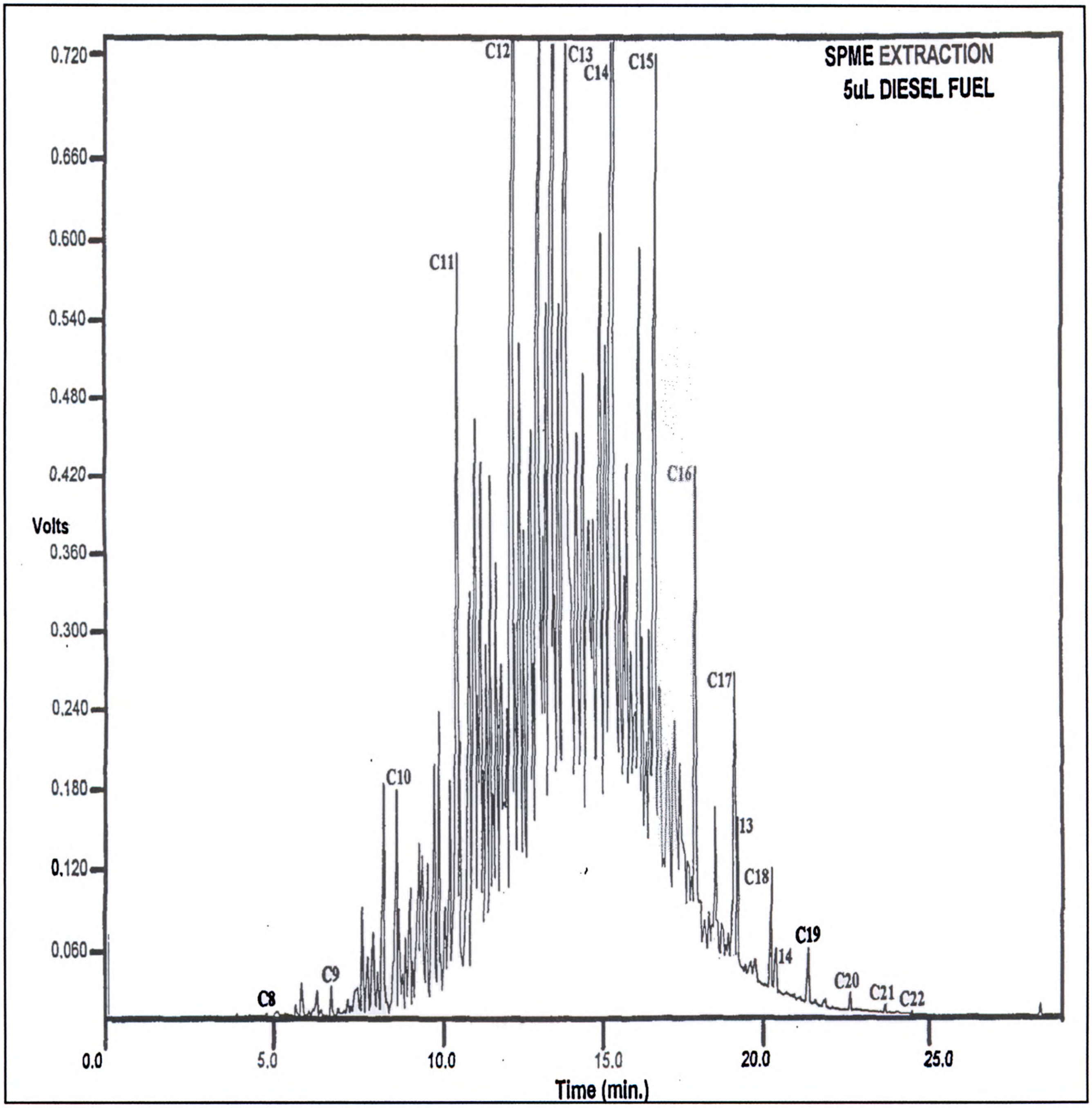
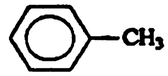
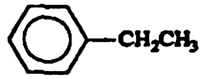
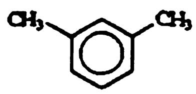
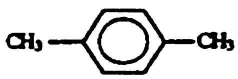
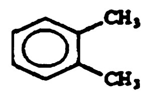
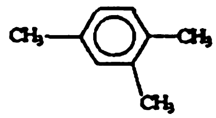
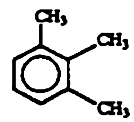
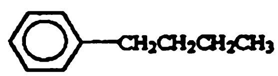
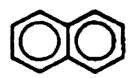
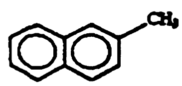
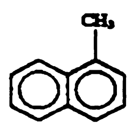


Figure 5. Chromatogram of the SPME extraction of diesel fuel.

TABLE 2—*Key to the peak identification of aromatic compounds used in this study.*

Peak Number	Name of Compound	Chemical Structure
1	Carbon Disulfide	S=C=S
2	Toluene	
3	Ethyl Benzene	
4	m & p-Xylene	 
5	o-Xylene	
6	1,2,4 Trimethyl Benzene	
7	1,2,3 Trimethyl Benzene	
8	n-Butyl Benzene	
9	Naphthalene	
10	2-Methyl Naphthalene	
11	1-Methyl Naphthalene	

Acrylic Enamel Reducer or Weathered Gasoline - You Make the Call

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PPG Industries Acrylic Enamel Reducers (AER) coded DTR600, DTR601, DTR602, DTR604, and DTR607 were analyzed to determine if any could be improperly identified as weathered gasoline during routine fire debris analysis.

Each of the five AERs were analyzed using capillary gas chromatography as neat liquids and extractions utilizing dynamic adsorption/elution with the charcoal needle trap method (Juhala and Beever 1986). DTR602 was also evaporated to provide samples with 25%, 50%, and 75% evaporation. Analyses of the standards and extracts were performed on a Hewlett-Packard 5890 Gas Chromatograph with a Millipore Millennium data station. Operating parameters are listed in Table 1.

The neat and extracted sample results were compared to standards of weathered gasoline to determine if there were enough characteristic peaks from any of the AERs to improperly identify any as weathered gasoline. All five AERs were different than gasoline as neat samples, but 75% weathered DTR602 showed enough characteristic peaks in the correct proportion to be confused with 90% weathered gasoline. These peaks can be seen in Figures 1 and 2 showing 75% weathered DTR602 and 90% weathered gasoline, respectively. The characteristic peaks present included the C3 alkylbenzenes, indane, C4 alkylbenzenes, and naphthalene. DTR602 does not contain 1 and 2 methylnaphthalene, but some of the gasoline companies have been leaving them out of their formulations. After careful scrutiny, it was determined that weathered DTR602 is different than weathered gasoline, but it is important that each analyst make this determination using their instrumentation and standard protocol.

The correct identification of a flammable liquid from fire debris is the prime concern of the arson analyst. This identification becomes even harder when chemical companies manufacture industrial solvents using some of the same components as gasoline. PPG Industries AERs are composed of mixtures containing toluene, xylenes, light aliphatic solvent naphtha, and light aromatic solvent naphtha in the same hydrocarbon range as gasoline. If DTR602 was weathered in a fire along with pyrolysis products, it is possible that it could be improperly identified as weathered gasoline.

REFERENCES

Juhala, J. A. and Beever, F. K. A sensitive, rapid, and economical method for analyzing fire debris using absorption elution techniques. *Arson Anal. Newsletter* (1986) 9(1):1-11.

Table 1. GC/FID Parameters		
Column	J&W DB-1, 0.25 mm x 15 M	
Carrier Gas	Helium, 46 cm/second linear velocity at 60°C	
Injector	250°C, split/splitless in split mode, 20:1 split ratio	
Detector	250°C	
Temperature Program	Initial Temperature	60°C
	Hold	1 minute
	Ramp	30°C/minute
	Final Temperature	270°C
	Final Hold	2 minutes

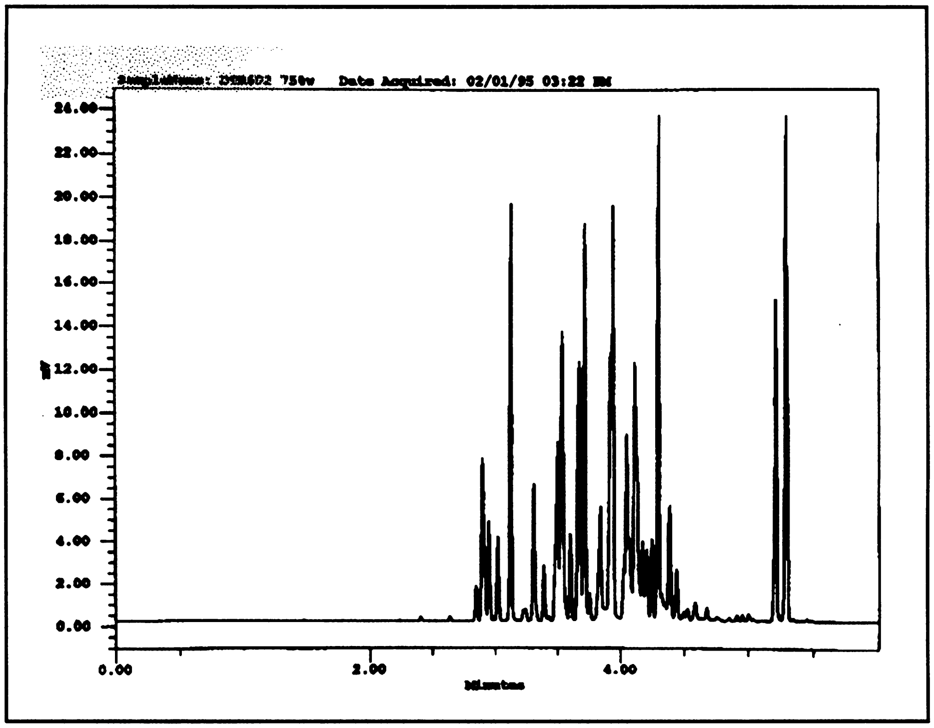

Figure 1. 75% weathered DTR602.

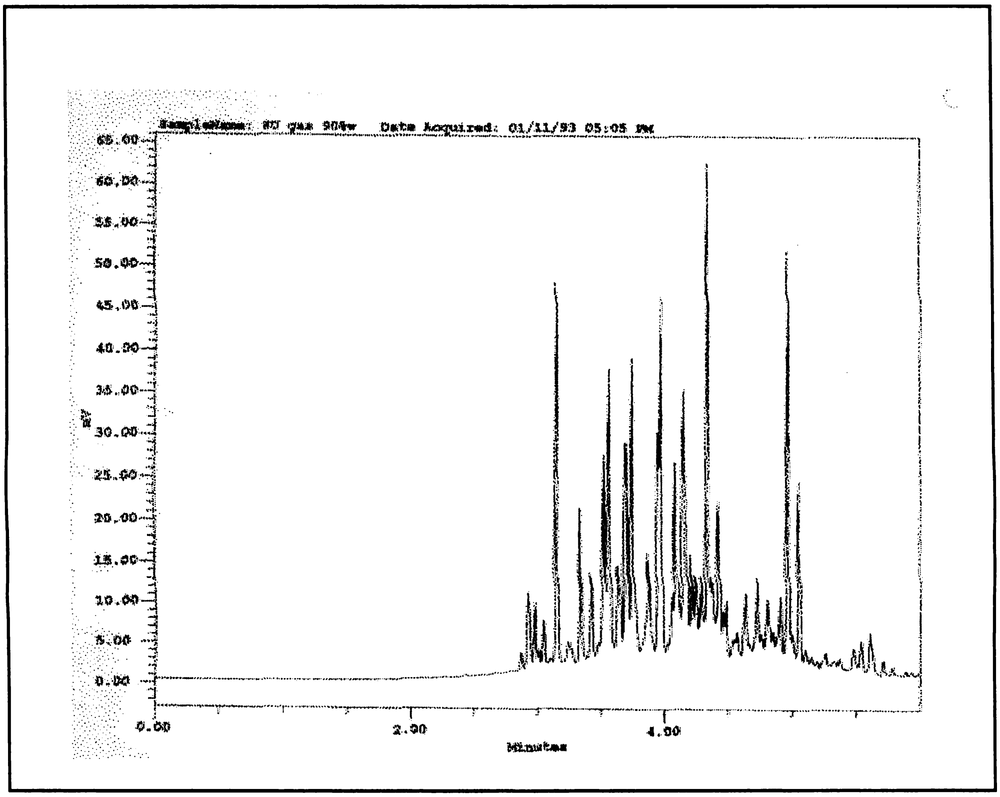

Figure 2. 90% weathered gasoline.

AUTHOR INDEX